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Article

Initial Characterization and Water Quality Assessment of Stream Landscapes in Northern Mongolia

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Abstract: A comprehensive monitoring project (2006–2013) provided data on hydrology, hydromorphology, climatology, water physico-chemistry, sedimentology, macroinvertebrate community and fish diversity in the Kharaa River basin in northern Mongolia, thus enabling, for the first time, a detailed characterization of the stream landscapes. Surface waters were categorized into separate “water bodies” according to their identifiable abiotic and biocoenotic features, subsequently creating the smallest management sub-units within the river basin. Following the approach of the European Water Framework Directive (EC-WFD), in order to obtain a good ecological status (GES), four clearly identifiable water bodies in the Kharaa River main channel and seven water bodies consisting of the basin’s tributaries were delineated. The type-specific undisturbed reference state of various aquatic ecosystems was identified in the assessment and used to set standards for restoration goals. With regards to water quality and quantity, the upper reaches of the Kharaa River basin in the Khentii Mountains were classified as having a "good" ecological and chemical status. Compared with these natural reference conditions in the upper reaches, the initial risk assessment identified several "hot spot" regions with impacted water bodies in the middle and lower basin. Subsequently, the affected water bodies are at risk of not obtaining a level of good ecological and/or chemical status for surface waters. Finally, a matrix of cause-response relationships and stressor complexes has been developed and is presented here. The applicability of management approaches is discussed to better foster the development of a sustainable river basin management plan. The application of natural references states offers a sound scientific base to assess the impact of anthropogenic activities across the Kharaa River basin.

Keywords: water quality; water bodies; ecosystem service; river type; risk assessment; Kharaa River; Mongolia

1. Introduction

Stream landscape conditions in northern Mongolia range from close to pristine in their upper catchments, to rivers that are substantially affected by anthropogenic factors in their middle and lower reaches. These impacts have been attributed to the region's rapid economic development, which has been largely driven by the exploitation of mineral resources (e.g., gold), population growth, urbanization and the expansion of agricultural and grazing activities.

Human activities have modified the environment at both global and national scales, to the point where researchers have proposed the term "anthropocene" for the current geological epoch, to emphasize mankind's dominating influence on the geology and ecohydrology across the planet [1,2]. The existence of regions with limited human impact has become extremely rare, as the majority of aquatic ecosystems in the world has been disturbed or altered in some way and thus have subsequently lost their pristine characteristics [3–9]. Even in the sparsely populated, remote stream landscapes of Mongolia, it is likely that anthropogenic influences will considerably alter these nearly pristine regions in the near future.

Mongolia, a landlocked country in north-central Asia, is characterized by an extreme continental climate with strong seasonal contrasts [10]. Located in the transitional zone between the great Siberian taiga and the Central Asian desert, the climate is characterized by long, dry winters and short summers. Large daily and seasonal temperatures fluctuations are common, with relatively high numbers of cloudless days and low precipitation of approximately 230 $mm \cdot yr^{-1}$, falling predominantly (85%) in the summer months. Mean monthly air temperatures in January range between minus 20 °C and minus 25 °C, with minimum air temperatures dropping to minus 40 °C. The maximum air temperature in summer can rise to 40 °C during the hottest parts of the day. A large percentage of the precipitation (between 85% and 95%) evaporates and is therefore not available for infiltration or runoff generation, particularly during the summer [11,12].

Fluvial drainage systems in northern Mongolia belong mostly to the Arctic Ocean Basin (AOB), with the Selenge River Basin (SRB, total catchment area of 459,000 km^2) being the major inflow to Lake Baikal (Figure 1) [13].

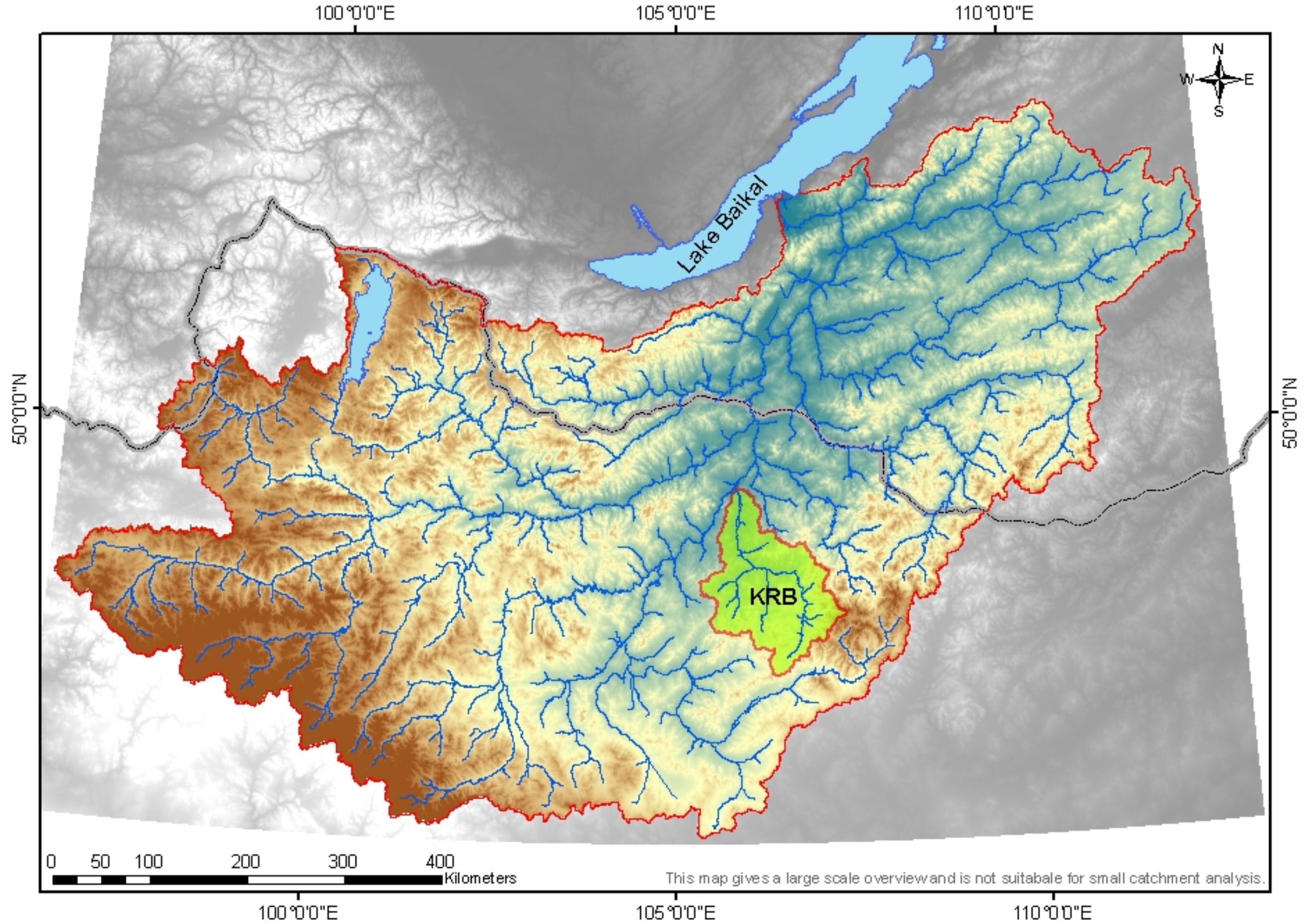

Figure 1. Orohydrographical map of the Selenge River Basin (SRB, catchment area 459,000 km^2) in northern Mongolia with the location of the Kharaa River Basin (KRB, catchment area 14,534 km^2).

The Kharaa River basin (KRB) is located within the SRB, positioned between latitudes 47.883 and 49.633° N and longitudes 105.316 and 107.366° E. The basin covers an area of 14,534 km^2 and is north of the capital Ulaanbaatar. An investigation of water quality and characterization of stream types was conducted in the KRB within the framework of a project focused on the development and implementation of a science-based Integrated Water Resource Management (IWRM) [14]. Various other research activities have also been carried out in and around the KRB in recent years [13–26].

The principal objectives of our current study on characterization and water quality assessment of stream landscapes were to:

(i) Characterize water bodies as basic units for water management planning;
(ii) Derive scientific based natural background conditions in the KRB for referencing purposes;
(iii) Identify ecological deficits in the Kharaa River as a consequence of diffuse and point source emissions (e.g., excess nutrients and heavy metals) and degradation of vegetation (which triggers erosion and causes increased riverine sediment loads);

(iv) Conduct an initial risk assessment to identify where there has been a failure to meet environmental criteria relating to a good chemical and ecological status for running surface waters in the KRB; and finally,
(v) Identify, localize and prioritize protection and rehabilitation measures.

The overall objective is to promote the discussion on water quality assessment and to establish the concepts of protection and rehabilitation measures for the future implementation of a river basin management plan (RBMP) that is based on objective scientific data.

1.1. The Physiogeographic Setting of the Kharaa River Basin

The Kharaa River originates in the Khentii Mountains in northern Mongolia and flows north-northwest joining the Orkhon River within the greater SRB. Based on digitized topographical maps, the length of the main river channel was determined, starting with km "zero" at the confluence between the Kharaa and Orkhon rivers (49.6316° N, 105.8335° E, 657 m a.s.l.) and ending at river km 313, at the confluence with the Mandalin Gol and Sugnugr Gol, the main source tributaries of the Kharaa River in the upper reaches (48.4343° N, 106.76621° E, 1091 m a.s.l.). The river name "Kharaa" is used only downstream of the river confluence from Mandalin and Sugnugr Gol [15].

From the headwaters in the southeast, to the outlet in the northwest, the Kharaa River cuts across several major morphological and geological units and fault zones of the Mongol-Baikal Lake tectonic system, including the main Mongolian lineament [16]. Most of the river basin is covered by grassland (59%) and forest (26%) with the portion of arable land only 11% [19] (Figure 2).

Based on distinctive geomorphology, geotectonics and climatology the KRB can be distinguished into three sections:

1. The upper reaches comprising the sub-basins 1 to 5 in Figure 2, are characterized by mid- to high mountain ranges of the Khentii Mountains and generate the highest specific runoff rates (average 2.45 $L \cdot s^{-1} \cdot km^{-2}$) of the entire river basin thus being the main water source ("water tower" [5]) for the lower catchment.
2. The middle reaches (sub-basins 6 to 8 in Figure 2) have lower specific runoff rates (average 0.7 $L \cdot s^{-1} \cdot km^{-2}$), the relief is dominated by broad valleys with significant terrace levels and hilly uplands with gentle slopes; the drainage pattern is confined to some active highly-sinuous channels which are interconnected with numerous abandoned channels in a fluvial floodplain.
3. The lower reaches (sub-basins 9 and 10 in Figure 2), also have low specific runoff and are typical open steppe and lowland landscapes with features of peneplain formation processes, where the vegetation of the fluvial floodplain has been degraded by overgrazing.

The long-term (1990–2012) average monitored discharge of the Kharaa River is approximately 11.5 $m^3 \cdot s^{-1}$ at the outlet of the basin (gauge station Buren Tolgoi, 49.5914° N, 105.8591° E). This is equivalent to a mean specific runoff of 0.83 $L \cdot s^{-1} \cdot km^{-2}$ [18].

The entire population of the Kharaa River basin is 147,000 (census data as of 2005, mean population density about 10 $inhabitants \cdot km^{-2}$), with most of the inhabitants living in the city of Darkhan (75,000 inhabitants), located near the river basin outlet [15].

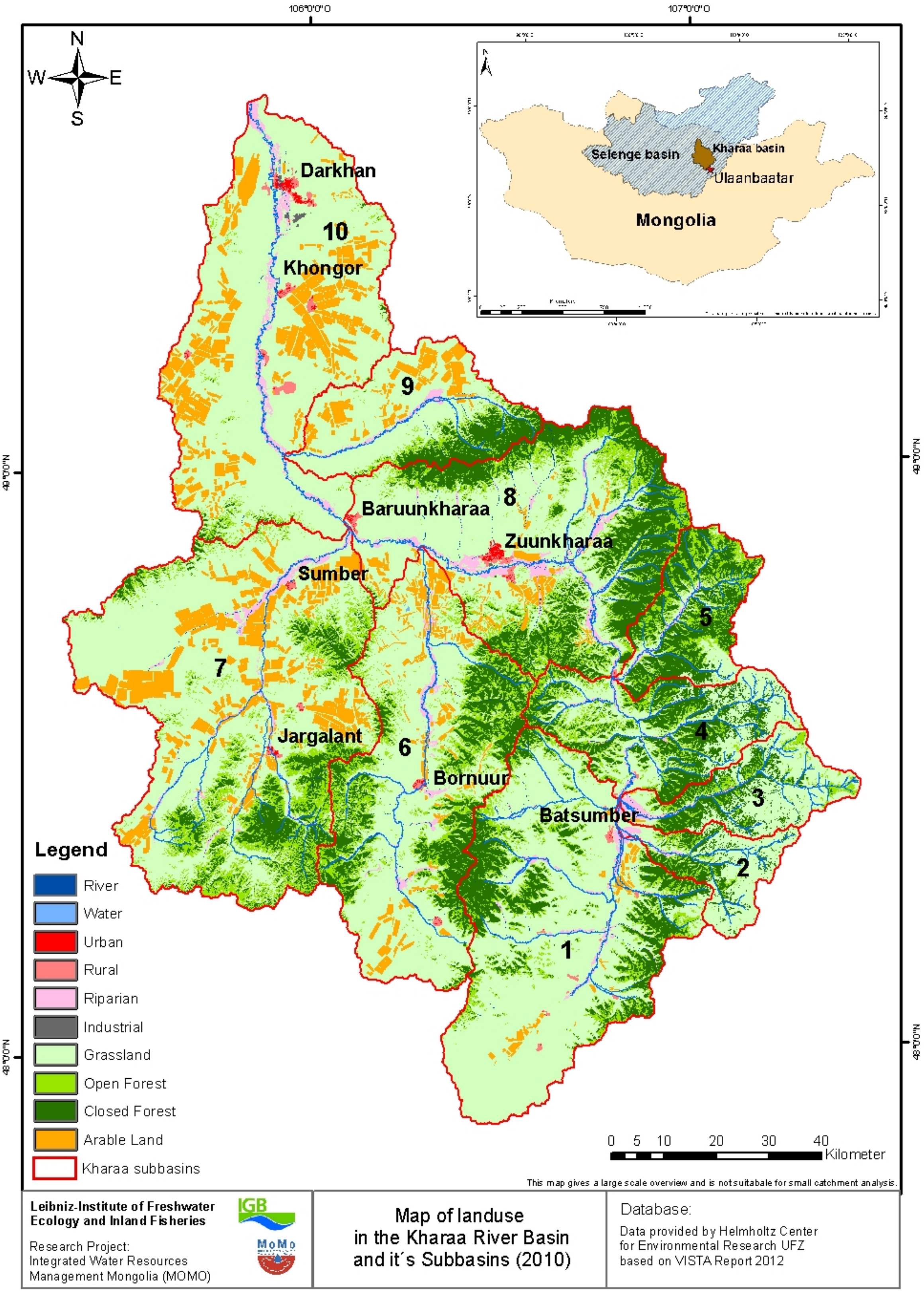

Figure 2. Land-use in the Kharaa River basin in 2010. The numbers in black indicate the individual sub-basins that have been chosen for nutrient emission and hydrological modeling purposes [15,17]. Note that the class of arable land also contains portions of fallow land. As shown in the overview map (upper right corner), the Kharaa River basin (dark area) is part of the Selenge catchment (hatched area), which drains into Lake Baikal.

Agricultural production on arable land is conducted using a rotation system, with wheat being the dominant crop, and to a lesser extent potatoes, which are commonly used as cash crops in the KRB [20]. Livestock grazing has been the principal land-use type in the catchment over the last decades. However, since the collapse of the former socialist system in 1990/1991, the de-regulation of pastoralism has led to increased herd sizes and a concentration of grazing near cities and on the river floodplains. Despite severe livestock losses due to a series of dry summers followed by winters with heavy snowfall (Mongolian; *Dzud*) in the period 1997 to 2003 and 2009/2010, the national stocking rate of grazing animals has increased dramatically from 25 million (1990) to recent record levels close to 50 million animals. The livestock numbers in the KRB are estimated to be currently around 1.5 million animals [20].

Another important driver of land-use changes is the mining sector. Due to the geological situation in the main Mongolian lineament, gold-mining has been well developed in the middle reaches with the focus of production occurring in the Boroo and Gatsuurt gold mining areas. Currently, more than 20 mines operate within the KRB [18,21].

1.2. Monitoring of Surface Water Quality in the KRB

As a part of Mongolia's freshwater quality monitoring network, the hydrochemical assessment of the surface water in the KRB has been conducted since 1986 by the Central Laboratory for Environment and Meteorology, IMHE [13]. The results from a monitoring study at five sampling sites (one site both upstream and downstream of Zuunkharaa, one site both upstream and downstream of Darkhan, and one site at Baruunkharaa, see Figures 2 and 3 and Table 1), for the period from 1986 to 2011 have been evaluated [13].

In addition to the state agency monitoring program, a long-term water quality monitoring program has been conducted under the research aims of the project entitled "Integrated Water Resources Management (IWRM) in Central Asia: Model Region Mongolia" (MoMo Phase I and II, http://www.iwrm-momo.de [27]) during the period 2007 to 2013. As a result of the water quality monitoring programme, a database was established for hydrochemistry (general physical-chemical parameters, major ions, nutrient and heavy metals), hydrology (long-term run-off data) and hydrobiology (community compositions of diatoms, macroinvertebrates and fish populations) in the KRB. The spatial allocation of sampling sites, wastewater treatment plants (WWTP), the mapped gold mines and other areas with contamination potential are shown in Figure 3.

The results of the long-term assessment of the water quality monitoring and ecological status in the KRB have been published in numerous reports and scientific papers [15,17,27–39]. Heavy metal pollution [21,40,41], eutrophication [15], a loss of habitats and biodiversity [15] and fine-grained sediment impacts [31,32,42] have been found to occur in the KRB.

Researchers at the Institute of Geography/Geoecology (Mongolian Academy of Sciences) have conducted surface water quality monitoring in the Orkhon River basin, including the Kharaa River, from 2009 to 2014. The physical-chemical measurements, major ions and nutrients were measured twice a year in surface waters during the ice free period, while heavy metal concentrations were determined in surface waters and sediments. Aluminium, mercury and arsenic levels were found to be greatly elevated in the streambed sediment of one of the Kharaa River's mid-catchment tributaries, the Boroo River, as well as in the main channel [22,43]. Within the middle reaches of the Boroo River, mercury concentrations were highly significant due to a 1956 explosion of a storage tank containing liquid mercury. Large quantities of this toxic heavy metal, which was and currently still is used during the amalgamation of gold in the small scale mining operations, were released into the surrounding environment contaminating the resident fauna. There were also considerable amounts of mercury known to have been released in the lower catchment during the Khongor incident in 2007 [40]. As a result of this heavy metal pollution in the basin there is a concern of uptake into the food chain and thus affecting human health by fish consumption also further downstream in the Russian part of the SRB [44].

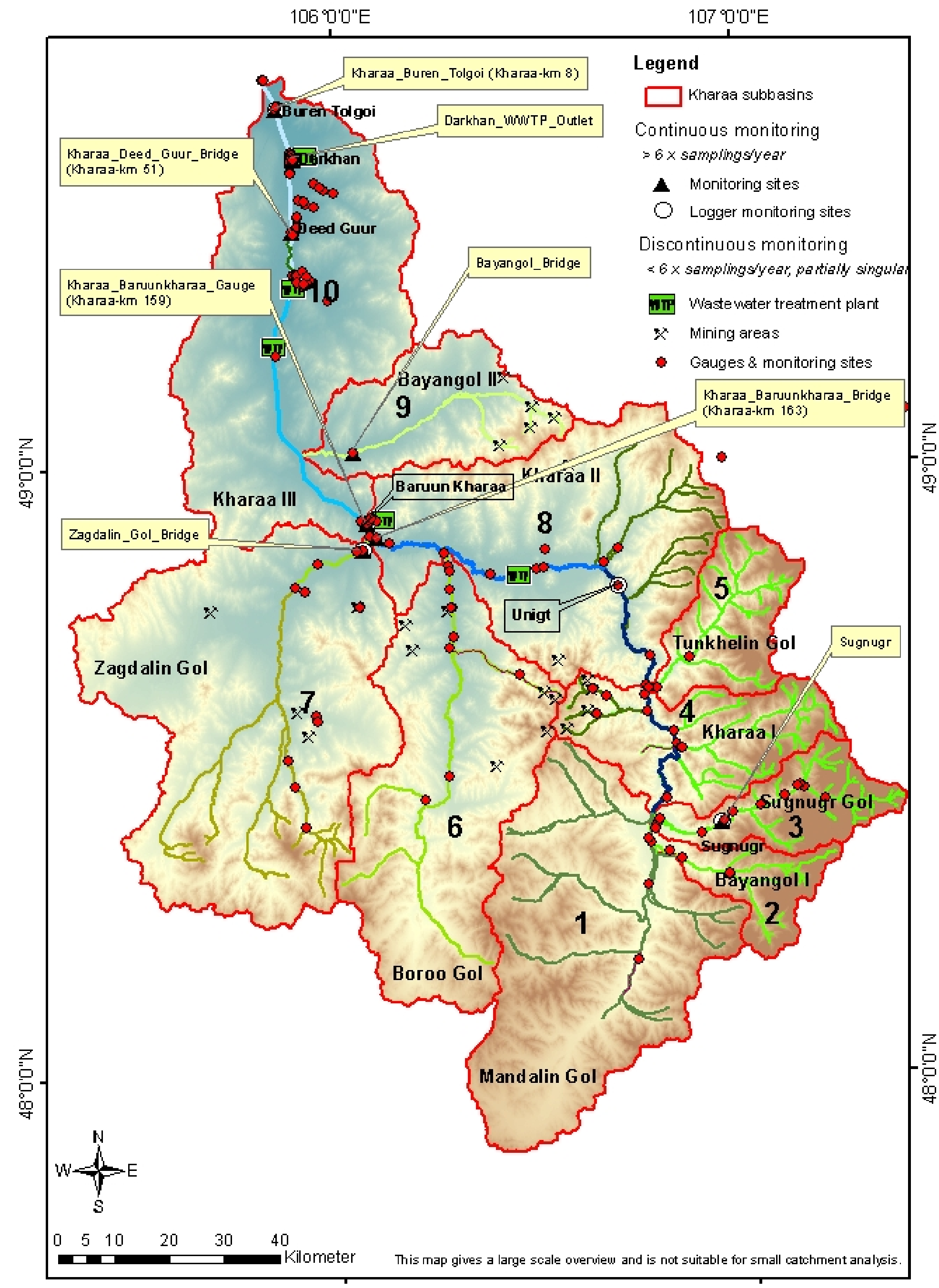

Figure 3. Continuous and discontinuous water quality monitoring in the KRB. In addition, the location of mining areas, contaminated areas and wastewater treatment plants (WWTP) is indicated. The numbers in black refer to the hydrological sub-basins in the text. The color of river network is explained in Figure 4.

Table 1. Sampling points for hydromorphology, discharge, physico-chemistry, macroinvertebrates, diatoms and fish. The unequivocal primary code ID (second column from left) allows the allocation of systematic site names for all locations (e.g., Sel_Kh10_001; Sel = Selenge River basin district. Kh = Kharaa river basin, 10 = Sub-basin 10 of KRB [15], 001 = numbers of water bodies and water usages (001–200 = Surface water bodies of running waters, e.g., rivers).

Sampling Point (MoMo) *Monitoring Site (IMHE)* **Kharaa Mileage (km)**	**Primary Code ID**	**Latitude (°N)**	**Longitude (°E)**	**Elevation (m a.s.l.)**
Kh_1. Buren_Tolgoi_Gauge/WQM Logger. *Kharaa Darkhan downstream* (Kharaa km 8)	Sel_Kh10_001	49.5914167	105.859116	664
Kharaa_Deed_Guur_Bridge. *Kharaa Darkhan upstream* (Kharaa km 51)	Sel_Kh10_008	49.3899	105.897183	703
Kh_2. Kharaa River. downstream of Darkhan	Sel_Kh10_003	49.52111	105.89469	673
Kh_3. Kharaa_Khongor	Sel_Kh10_009	49.31932	105.9003	708
Kh_3.5. Kharaa_ds_Baruunkharaa	Sel_Kh08_012	48.93874	106.01187	783
Kh_4. Kharaa River. downstream of Baruunkharaa	Sel_Kh10_011	48.91589	106.06043	787
Kharaa_Baruunkharaa_Gauge_WQM_Logger. *Kharaa-Baruunkharaa.* (Kharaa km 159)	Sel_Kh10_012	48.91165	106.075033	796
Kh_5. Kharaa River. upstream of Baruunkharaa	Sel_Kh08_002	48.87986	106.1299	804
Kh_6. *Kharaa-Zuunkharaa downstream*(Kharaa km 203)	Sel_Kh08_003	48.82686	106.37845	840
Kharaa_Zuunkharaa_bridge. *Kharaa-Zuunkharaa upstream* (Kharaa km 219)	Sel_Kh08_004	48.8332	106.49383	859
Kh_7. Kharaa River. upstream of Zuunkharaa bridge	Sel_Kh08_005	48.8346	106.50909	865
Kh_8. Kharaa_Unigt_discharge_Logger	Sel_Kh08_006	48.80335	106.6922	915
Kh_8.3	Sel_Kh08_011	48.67167	106.77667	944
Zagdalin_Gol_Bridge_WQM_Logger	Sel_Kh07_002	48.86691	106,06457	796
Kh_8.5. Kharaa River. Railway Station km 290	Sel_Kh04_002	48.54406	106.82719	1048
Sug_2	Sel_Kh03_005	48.45431	107.09087	1304
Sugnugur_WQM_Logger	Sel_Kh03_009	48.41322	106.93521	1180
Sug_1	Sel_Kh03_010	48.39673	106.8839	1159
Mand_2	Sel_Kh01_002	48.31394	106.75099	1127
Mand_1	Sel_Kh01_001	48.18985	106.72505	1179
Tun_1	Sel_Kh05_002	48.63501	106.78388	1005
Shiv_1	Sel_Kh08_008	48.86604	106.69608	938
Bor_0.5	Sel_Kh06_002	48.84052	106.27373	830
Zag_1	Sel_Kh07_001	48.89111	106.08071	801
Gatsuurt_brook_ds_Goldmine	Sel_Kh04_008	48,62381	106,66052	1126
Baya_1	Sel_Kh02_004	48.3672	106.80424	1121

1.3. Water Management in Mongolia

The beginning of the new millennium saw an increased awareness in Mongolia regarding the vulnerability of the country's water resources in terms of quality and quantity and the role water will play as a basis for the country's socio-economic development [33]. As a result, a policy focusing on the sustainable use of water resources has gradually been developed. Mongolia's Water Law (2012) [45] declared Integrated Water Resource Management (IWRM) to be implemented at the river basin scale, as the core concept for national water management [36,46].

Mongolia has continually reformed its water policies with the objective to solve the main challenges of institutionalizing river basin management (RBM) and IWRM. However, the continued ongoing transformations in other political, social and economic sectors sometimes constitutes additional challenges for the implementation of these reforms at both a national and river basin level [33,36]. Mongolia's water sector is very complex, involving six national ministries, 13 main agencies and several minor agencies [47]. In total, eight national laws deal with the protection, use and restoration of water resources. Moreover, there is overlapping legislation with regards to the protection and sustainable use of air, land, forest, wildlife and mineral resources [48]. The Water Law of 2012 [45] was intended as an "umbrella", coordinating all laws and by-laws concerning the water sector. One of its main requirements is the development of a national IWRM plan for Mongolia and each of the country's 29 river basins [49].

The resulting River Basin Management Plans (RBMPs) are expected to fulfil four main tasks: (1) to assess the status of each specific river catchment; (2) to prevent potential water scarcity; (3) to protect water resources against pollution and (4) to allocate and use water resources in the most efficient way. The recommended measures should be implemented from 2015 to 2021 [47].

2. Materials and Methods

The Mongolian water sector is in a period of dynamic institutional transition [49], thus addressing problems of data scarcity requires a flexible and adaptable approach, such as proposed by the Integrated Water Resource Management (IWRM) concept. In addition, it is argued that the methodology of the EC Water Framework Directive (EC-WFD, EC 2000/60/EC) [50], can only partly serve as a model for IWRM implementation at a river basin-scale in Mongolia [33]. The fundamental difference in the assessment of European waterways, is the consistency in the definition of the reference conditions for the classification of surface waters, as well as the need to develop monitoring tools to integrate the structure and functioning on the ecosystem level. Following this approach, our objectives are set relative to the ecological quality rather than physico-chemical thresholds, as in existing Mongolian legislation. Thus, our reference screening criteria did not only incorporate physico-chemical, hydro-morphological (Section 2.4) and pressure criteria to identify reference sites, but also the spatial and temporal variability within the biological communities (Section 2.3). The Europe wide applicability of the EC-WFD methodology covers also the Pannonian ecoregion (including all of Hungary) with the westernmost areas of the Eurasian forest steppes, which form part of a band from Eastern Europe almost to the Pacific coast. This vast system consisting of alternating forest and grassland patches forms a mosaic-like landscape, such as the Daurian forest-steppe in northern Mongolia (Section 3.1).

One important provision of the EC-WFD, is that all assessments of surface waters must be based on sound surface water typologies. Consequently, we used the descriptors of the "Working Group of the Federal States on water issues" (Bund/Länder-Arbeitsgemeinschaft Wasser, LAWA) [51,52] subcommittee "Biological Stream Assessment and Inter-calibration in Accordance with the EC-WFD" to differentiate between water body types based on their specific abiotic and biotic characteristics.

We defined the following procedure for the assessment of the chemical and ecological status of the Kharaa River basin:

(a) Delineation of stream types in accordance with Pottgiesser and Sommerhäuser [52];
(b) Classification of water bodies (according to EC-WFD, Article 2, point 10 and EC-WFD) [50];
(c) Characterization of natural reference conditions to gain information on natural background levels;
(d) Initial assessment (surface water quality and ecology) of distinct water bodies;
(e) Determination of protection/development measures.

2.1. Methodology and Descriptors of Stream Types

Obligatory and optional descriptors used by LAWA [51,52] to delineate stream types include ecoregion, altitude, geology and geomorphology according to the river landscapes and regions [53], stream slope and size.

As there has been no stream type classification system established in Mongolia prior to this research it was decided to apply an approach which was originally designed for German rivers [52]. Although applying this approach to Mongolian rivers does certainly have limitations, the overall character (hydro-dynamics, morphology, and general fauna elements) of the streams and rivers in the KRB are similar to running waters in mountainous and steppe regions of central Europe. Therefore, this approach including certain specific adaptations, especially with regards to the fauna assessment, is assumed to be sufficient for a first basal description of the Kharaa River catchment water bodies. The profiles of the identified river types in the Kharaa River catchment (Supplementary Material S.1.) include a general hydro-morphologic characterization. The numerical information gives representative ranges typical for a certain stream type.

As a consequence of missing reference sites for some river types, reference taxa lists were not included but a more general ecological characterization of the aquatic communities are provided as a result of expert knowledge and analysis. There is need for further research including different geographic and climatic regions to provide a more detailed and reliable fauna dataset, which can only be achieved with commissioned research projects in cooperation with Mongolian state agencies. Furthermore, it should be noted that only the water bodies of the KRB have been included into the classification given in the Supplementary file (Supplementary Material S.1.), and therefore, it cannot be applied without adaptations to other regions in Mongolia where it is most likely that additional river types first need to be included to achieve a robust classification of Mongolia's running waters in the future.

2.2. Delineation of Surface Water Bodies in the KRB

The definition of a water body is given by the European Community Common Implementation Strategy (EU CIS) Guidance Document No. 2 [54], as being the smallest management sub-unit within a river basin that unambiguously represents a river section of coherent hydrology and geology of the overall status and thus identifies the most appropriate management unit. This methodology provides the base to allocate each water body to a dominant stream type, its ecoregion and its characteristic biocenosis. We defined a unique primary code key to identify all monitoring sites (including the levels of project driven, state driven and other research driven monitoring sites in the KRB) and to allocate them to distinct water bodies (Table 1).

The description of the water bodies in the KRB was conducted based on geographic position, altitude, size and geology according to "System A" of the EC-WFD [50], which is a well-established method in Europe and was assumed to be applicable due to the similarity of streams and rivers of the KRB and those known from mountainous regions in central Europe. In a subsequent step, this abiotic differentiation was compared with divisions based on existing biological data and expert judgement.

For a proper description of the surface water bodies, they must not overlap with each other. If there are significant differences in the status of the different parts of a river, it must be sub-divided into separate water bodies to achieve the desired environmental objective in the most cost effective way [55,56].

2.3. Biological Data

To ensure a comprehensive and robust biological assessment, data on macroinvertebrate and fish populations were collected from 21 sampling sites (Table 1) and were compiled by the IWRM research project "MoMo" [27]. In addition, the state surveillance monitoring data from the Mongolian Academy of Sciences (MAS) concerning the diatom assemblages were also included.

Macroinvertebrates and fish were sampled during field surveys conducted between 2006 and 2012, to gather information regarding species compositions and to then identify possible environmental impacts using bio-assessment methods. A standardized sampling procedure (multi-habitat sampling) was used to analyze aquatic macroinvertebrates at each sampling site [57]. The major habitats on the river substrate were sampled in proportion to their occurrence within a chosen sample reach (approx. 5–10 times the river width). A detailed description of the sampling procedure was given by Hofmann *et al.* [15] and Avlyush *et al.* [28]. After sample analysis, a meaningful set of robust structural and functional macroinvertebrate community metrics was applied in order to assess the ecological status at each corresponding sampling station [15] (Table 2).

The macroinvertebrate fauna of the KRB was composed of 211 different subgenera and genera or higher taxonomic groups belonging to 24 orders [15]. Altogether 131 species belonging to EPT (63 **E**phemeroptera, 18 **P**lecoptera, 50 **T**richoptera) have been identified. For estimation of reference conditions, the community compositions of sites with the lowest anthropogenic impact from the first two sampling campaigns were assumed to be sufficient. From the metric sets used, a preliminary evaluation of the ecological status at the sampling sites was made [15].

During surveys with higher temporal resolution, the seasonal variability in the assessment results could be detected at different sites. This was largely identified as life cycle determined changes in the aquatic macroinvertebrate community due to a large proportion of insect species with aerial stages. Best assessments have resulted from analyzing macroinvertebrate communities during the summer months from June to August and therefore this period is recommended for macroinvertebrate biomonitoring activities in Mongolia in the future.

Table 2. Threshold values of metrics used for ecological quality assessments by benthic invertebrate assemblages in the KRB. For explanation of water bodies and river types see Tables 4 and 5.

Metric Set	Ecological Quality				
	Excellent	**Good**	**Moderate**	**Poor**	**Bad**
Water Bodies of Kh_Main_1, Kh_Main_2, Kh_Trib_2					
Taxa richness	40	30	25	20	<20
Plecoptera taxa	4	3	2	1	0
Ephemeroptera taxa	15	13	10	5	<5
Percentage of EPT individuals (%)	50	40	30	20	<20
Shannon diversity	2.2	2	1.5	1.2	<1.2
Percentage of fine substrates colonizer's density (%)	15	30	50	70	>70
Water Bodies Kh_Trib_1, Kh_Trib_3, Kh_Trib_4, Kh_Trib_6					
Taxa richness	30	25	20	15	<15
Plecoptera taxa	4	3	2	1	0
Ephemeroptera taxa	12	10	8	5	<5
Percentage of EPT individuals (%)	50	40	30	20	<20
Shannon diversity	2.2	2	1.5	1.2	<1.2
Percentage of fine substrates colonizer's density (%)	30	40	60	80	>80
Water Bodies Kh_Main_3, Kh_Main_4					
Taxa richness	40	30	20	15	<15
Ephemeroptera taxa	15	13	10	5	<5
Percentage of EPT individuals (%)	50	40	30	20	<20
Shannon diversity	2.2	2	1.5	1.2	<1.2
Percentage of fine substrates colonizer's density (%)	30	40	60	80	>80

The bio-assessment of fish communities was completed using standardized electrofishing methods. In order to allow comparability between sampling sites, a catch per unit effort (CPUE) approach was used. During the investigations in the Kharaa River catchment, 14 fish species belonging to nine families were recorded [15]. These represent 64% of the total species inventory of the Selenge watershed [58]. The number of individuals caught at a specific sampling site were counted. Species were identified on site and total length was measured. For the ecological quality assessment, the fish-based assessment system (FIBS) [59] was used. As no reference data for fish communities was available for the assessment, Mongolian and German ichthyologists developed a reference list for the different ecoregions considering the relative abundances of each fish species (Table 3).

With respect to the diatom assemblages a total of 338 species belonging to 58 genera, comprised nearly 65% of the 516 taxa listed in Mongolia [60]. The research results on diatom assemblages in the KRB and its possible application as a bio-assessment tool are yet to be published.

Table 3. Fish species composition used as reference for the ecological assessment of rivers in the KRB.

Fish Species	Relative Abundances (%) per River Type			
	Mid-Sized and Large Lowland Rivers Dominated by Sand and Loam	**Large Gravel Rich Highland Rivers**	**Small Siliceous Highland Rivers Dominated by Coarse Substrate**	**Small Siliceous Highland Rivers Dominated by Fine Substrate**
euciscus idus (Linnaeus. 1758)	2.5	-	-	-
Silurus asotus (Linnaeus. 1758)	0.5	-	-	-
*Thymallus baicalensis (*Dybowski. 1874)	0.5	6.0	15.0	0.5
Perca fluviatilis (Linnaeus. 1758)	1.5	-		-
Phoxinus phoxinus (Linnaeus. 1758)	0.5	62.0	55.0	60.0
Carassius gibelio (Bloch. 1782)	15.0	-	-	-
Esox lucius (Linnaeus. 1758)	0.5	0.5	-	-
Cyprinus carpio (Linnaeus. 1758)	2.5	-	-	-
Brachymystax lenok (Pallas. 1773)	0.5	2.5	8.0	0.5
Lota lota (Linnaeus. 1758)	2.5	0.5	0.5	0.5
Barbatula spp.	-	10.0	20.5	8.0
Leuciscus baicalensis (Dybowski. 1874)	56.5	10.0	-	20.0
Acipenser baerii baicalensis (Nikolskii. 1896)	0.5	-	-	-
Rutilus rutilus lacustris (Pallas. 1814)	1.0	-	-	-
Cobitis melanoleuca (Nichols. 1925)	15.0	6.0	0.5	10.0
Hucho taimen (Pallas. 1773)	0.5	2.5	0.5	0.5
Sum	100	100	100	100

2.4. Abiotic Data (Physico-Chemistry, Hydrology, Hydromorphology)

The physico-chemical data is based on long-term surveillance monitoring by Mongolian authorities (IMHE, data available since 1986 for two stations upstream and downstream of Darkhan, Table 1), as well as the projects surveillance monitoring with detailed longitudinal stream surveys in spring, summer and autumn from 2006 to 2013. Total nitrogen, ammonium, nitrate, nitrite, ortho-phosphate and total phosphorus were selected as water quality parameters for nutrients. As pollution indicators 11 heavy metal and metalloid elements (Al, As, Cd, Cr, Cu, Fe, Mn, Hg, Ni, Pb, Zn), as well as chloride and boron were selected. All parameters were analyzed in German laboratories (Berlin and Magdeburg) according to the national standards for quality assurance of water analyses.

Furthermore, three water quality measurement stations were installed at different locations in the catchment in the summer of 2011 to continuously monitor the dynamics of water quality parameters. These stations were located at: (a) Station Buren Tolgoi close to the catchment outlet approximately 15 km north of the city of Darkhan (Table 1, sub-basin 10 in Figure 3); (b) Station Baruunkharaa in the middle reaches of the catchment, adjacent to the intense agricultural and mining areas (Table 1, sub-basin 8 in Figure 3); (c) Station Sugnugr in one of the pristine headwaters in the Khentii Mountains (Table 1, sub-basin 3 in Figure 3). All three stations were equipped with optical YSI 6820 V2 probes (YSI Inc., Yellow Springs, OH, USA) that measured dissolved oxygen, pH, temperature and electrical conductivity at 15 min time steps during the ice free months from June to September 2012. All of the data was imported into a database and following an outlier separation, statistical analysis was undertaken to compare each station (Supplementary Material S.2.).

The hydro-morphological situation along the Kharaa River was mapped during field surveys in 2006–2007 [30] and during 2009–2011. Six main parameters and 31 sub-parameters were recorded at river sections of 100, 500 or 1000 m lengths and evaluated on a seven step scale. The main parameters included (i) development of the river course; (ii) longitudinal profile; (iii) morphology of the river bed; (iv) cross-sectional profile; (v) morphology of the river banks and (vi) surroundings (until 100 m on both sides of the bank). The details of the assessment protocol are given in Landesamt für Natur, Umwelt und Verbraucherschutz, Nordrhein-Westfalen, Germany, LaNUV [61].

The hydromorphological findings provide proof for minimal human induced changes and alterations of the natural dynamics of discharge and river bed morphology. Cut-off meanders and dams exist only near Darkhan at the bridge of Deed Guur (Supplementary Material S.1., LAWA river type 15, picture 4). Near Zuunkharaa and Buren Tolgoi, water is abstracted via irrigation channels. In general, the Kharaa River is a free flowing, meandering hydrological system without any weirs and reservoirs. However, the reference conditions for the natural dynamics of river floodplains are existent only in parts of the upper, middle (near sampling site Kh_8, Table 1) and lower most reaches (at the confluence of the Orkhon and Kharaa rivers, Supplementary Material S.1., LAWA river type 15, pictures 2 and 3), due to extensive livestock grazing. Thus the decline of riparian vegetation and its biodiversity is a significant ecological threat in many parts of the river course.

2.5. Initial Risk Assessment of Surface Water Bodies in the KRB

The preliminary risk assessment indicated the KRB failed to obtain a good environmental rating for both chemical and ecological standings for running surface waters. The assessment was performed as follows:

(a) For each individual surface water body a rating matrix (Supplementary Material S.3., Tables S1 to S11) was developed;
(b) Definitions of indicators and their ranges are included;
(c) The assessment is based on the natural reference status. For physico-chemical indicators the natural reference conditions are given by the values of the surface water body group Kh_Trib_2 (Khentii reference). For the biological assessment the reference conditions of the quality components “macroinvertebrates” and “fish fauna” have been used. Hydromorphological reference conditions were monitored separately;
(d) Erosion was integrated as part of the suspended load and was considered as turbidity within the physicochemical characteristics;
(e) Heavy metals were investigated with a focus on priority substance concentrations;
(f) For the map visualization the “Initial risk assessment of surface waters in the KRB” was chosen to reflect a traffic light color system: red = at risk, yellow = possibly at risk, green = not at risk, grey = no data (Supplementary Material S.3.);

(g) Additionally, the allocation of these colors followed the principle of the worst case scenario. Thus the worst result of an individual indicator dictates the final overall rating. For example, if only one quality component of an individual water body lies within the red range, the entire water body is marked in red color. The detailed data background is shown in Tables 7 to 10 and in Supplementary file, Supplementary Material S.3.;
(h) The main aim of the risk assessment map is to allow for the visualization of the situation at a glance. Detailed information is provided in the Supplementary files, Supplementary Material S.3. (Tables S1 to S11);
(i) For reasons of scale, the map allows only an overview and not an exact allocation.

Finally, the results were summarized and visualized in the preliminary map of the risk assessment (Section 3.5). To show at a glance, if the environmental objective of a good chemical and/or ecological status of running waters was achieved, three different categories were distinguished:

- **Surface water body at risk (red)**: running waters with a sufficient data base for the ecological and chemical status, and substantial evidence of existing deteriorations which make a good chemical and ecological status unlikely to be attained.
- **Surface water body possibly at risk (yellow)**: running waters with evidence of deteriorations in single cases, whose delineations is aggravated due to incomplete and lacking data base and where the attainment of a good chemical and ecological status is unclear.
- **Surface water body not at risk (green)**: running waters in the source area of the Khentii Mts. with very low population density, low land-use intensity, drinking water usage of running waters with good to very good water quality (e.g., Sugnugr Gol in the Khentii Mts.). The attainment of a good chemical and ecological status has been identified.

3. Results and Discussion

3.1. Profiles of Stream Types in the KRB

The KRB falls into two ecoregions, the Transbaikal coniferous forest and the Daurian forest steppe with grasslands and shrublands. The open steppe vegetation is a combination of pine (*Pinus silvestris*) and aspen (*Populus tremula*) amidst steppe flora.

By adapting the approach of Pottgiesser *et al.* [51] the rivers in the KRB could be assigned to five different biocenotically relevant stream types, see Table 4, Supplementary file, Supplementary Material S.1.

Altogether five stream types out of the 25 German ones could be identified in our study. Large rivers (stream types 10 and 20) were not included as a different assessment scheme has to be used for these types [62].

Table 4. Description of specific river types in KRB, their eco- and sub- regions and corresponding river types and type numbers according to German LAWA classification [51,52].

Ecoregion	Subregion (Geomorphology. Vegetation)	KRB Specific River Type (Bedrock. Altitude. Examples of Rivers)	Corresponding River Type (Type Numbers According to German LAWA Classification Scheme [1])
Transbaikal coniferous forest Realm: Palaearctic Biome: Boreal forest Taiga West slopes of Khentii Mts. with transition to the fault zone of Khangai/Khentii (Plutonites. Metamorphites) (Khentii Mountains)	Middle mountains with periglacial driven morphodynamics. V-shaped and flat-floored valleys (coniferous forest and mountain steppe with transition to Siberian taiga)	Small siliceous highland rivers dominated by coarse substrate (Granitoid-complex in Paleozoic sedimentary rocks Elevation >1100 to 2800 m a.s.l. Sugnugr, Tunkhelin)	**Type 5** Small coarse substrate dominated siliceous highland rivers
		Small siliceous highland rivers dominated by fine substrate elevation 900 to 1100 m a.s.l. (Kh_Trib_1 (Mandalin Gol), Kh_Trib_3 (Shivertin Gol), Kh_Trib_4 (Boroo Gol), Kh_Trib_5, Kh_Trib_6 (Zagdalin Gol)	**Type 5.1** Small fine substrate dominated siliceous highland rivers
	Narrow valley with steep flanks cutting its way into the basement rocks. Saucer shaped valleys (mixed forest, mountainous steppe)	Large gravel rich highland rivers (paleozoic greywacke with intrusions of granite und granodiorite) Elevation 900 to 1100 m a.s.l. Kharaa main river. water bodies Kh_Main_1 and Kh_Main_2	**Type 9.2** Large highland rivers
Daurian Forest steppe. Realm: Palaearctic. Biome: temperate grasslands and shrublands; Eastern foothills of Selenge-Orkhon mountainous area (Plutonites and Vulcanites. Basalt domes) (Selenge Orkhon mountainous area)	Mountain pediments and peneplains with broad multiple-staged fluvial terraces and broad flat floored valleys. mountainous steppe	Small lowland rivers dominated by sand (Quaternary/Holocene Sediments on top of paleozoic metamorphites and sedimentary rocks) Kh_Trib_7, Bayangol	**Type 14** Small sand-dominated lowland rivers
	Low undulated peneplains with alluvial fans. Loess cover and aeolian sand. Broad loess-covered valleys. transition to open steppe grassland	Mid-sized and large lowland rivers dominated by sand and loam (Quaternary/Holocene sediment rocks with isolated vulcanite deposits) elevation 600 to 900 m a.s.l. Kharaa main river. water bodies Kh_Main_3 und Kh_Main_4	**Type 15** Mid-sized and large sand and loam dominated lowland rivers

Notes: [1] The river type numbers in the right column refer to the German LAWA typology [52].

3.2. Surface Water Bodies as Water Management Units

A water body is characterized by similar environmental conditions [50]. In special cases, a whole river, stream or canal can be a "water body" but in many cases, changing environmental conditions along the river course require a division into separate water bodies and the application of different reference conditions. Furthermore, also abrupt changes in the ecological status (caused for example by point source emissions) require the separation into different water bodies to achieve the desired environmental objective in the most cost-effective way. The differentiation of surface water bodies led to a subdivision of the Kharaa River main course (total length 313 km) into four different water bodies. For the tributaries with a total river length of 1637 km, seven distinct water bodies could be delineated (Figure 4, Tables 5 and 6).

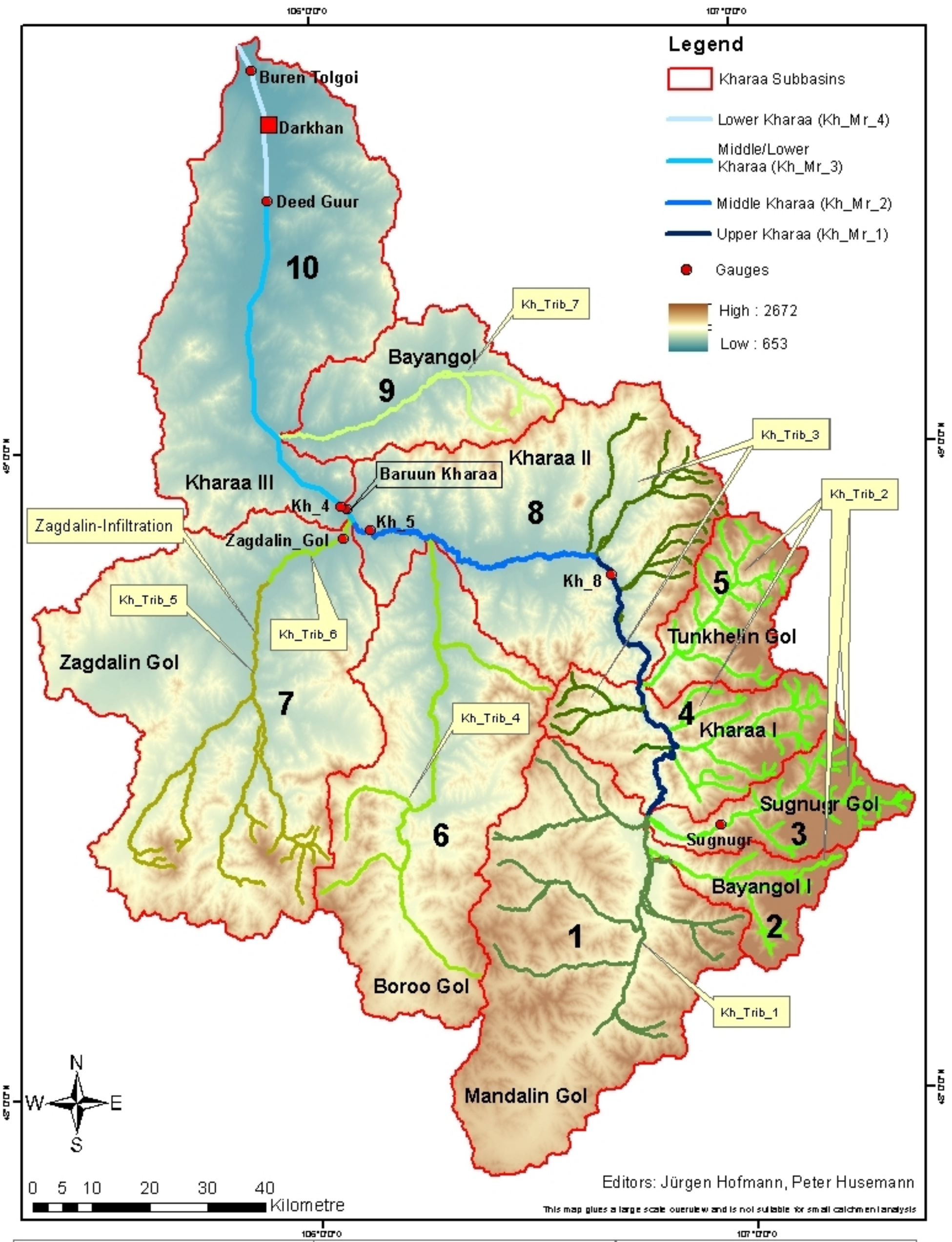

Figure 4. Description of surface water bodies, location of monitoring sites and delineation of the KRB into 10 sub-basins (No. 1–10).

Table 5. Surface water bodies in the KRB, their description and biocenotic regions (Figure 4). The right column "MONERIS sub-basins" refers to the description of hydrological sub-basins applied for nutrient emission modeling with MONERIS [15]. Biocenotic regions and hydrography according to Berner [30].

Main River Course of the Kharaa (Kharaa River Main Channel = Kh_Main)			
Code-Nr. of Water Body (WB)	*Short name of WB*	*Description of spatial delineation of WB. river kilometre index*	*MONERIS Sub-Basin (Figure 2)*
	Length (km)	*Biocenotic Region*	
		Hydrography (means of river width, slope and mean depth)	
Kh_Main_1	Upper Kharaa	The upper Kharaa River downstream of the confluence with the tributaries Mandlin Gol and Sugnugr Gol (*ca*. 7 km north of Batsumber), until upstream from the influent of tributary Shivertin Gol (Kh_8) (Kharaa km 218 to Kharaa km 313)	4, 8
		Hyporhithral	
	95 km	Width: 17–25 m. Gradient: 3 m/km. Mean depth: 0.3 to 0.5 m	
Kh_Main_2	Middle Kharaa	The middle Kharaa River downstream of the tributary influent from Shivertin Gol, until upstream of the influent from the tributary Zagdalin Gol (Kharaa km 159 to Kharaa km 218)	8
	59 km	Hyporhithral	
		Width: 20–30 m. Gradient: 2 m/km. Mean depth: 0.4 to 0.5 m	
Kh_Main_3	Middle/Lower Kharaa	The middle Kharaa River downstream from the influent of the tributary Zagdalin Gol, until upstream of the Deed Guur bridge, south of Darkhan (Kharaa km 51 to Kharaa km 159)	8, 10
	108 km	Epipotamal	
		Width: 19–30 m. Gradient: 1 m/km. Mean depth: 0.4 to 0.5 m	
Kh_Main_4	Lower Kharaa	The lower Kharaa River downstream of the Deed Guur bridge, until the confluence of the Kharaa River with the Orkhon River (Kharaa km 0 to Kharaa km 51)	10
	51 km	Epipotamal	
		Width: 22–38 m. Gradient: 0.7 m/km. Mean depth: 0.5 to 1.0 m	
Total	313 km	Total length of Kharaa main river	
Tributaries of the Kharaa River (Kharaa River Tributaries = Kh_Trib)			
Code-Nr. of WB	*Short name of WB*	*Description of spatial delineation of WB*	*MONERIS Sub-Basin (Figure 2)*
	Length (km)	*Biocenotic Region*	
Kh_Trib_1	Mandalin	Mandalin Gol	1
	291 km	Hyporhithral with transition to Epipotamal	
Kh_Trib_2	WB Khentii Reference	Water body group (WBG) of the rhitral tributaries from the Khentii Mts. with natural background conditions (sub-basin 2 to 5 e.g., Bayangol-I, Sugnugr Gol, Tunkhelin, Ulgii Gol) orographic right of the Kharaa main river course	2, 3, 4, 5
	583 km	Epi-. Metarhithral	

Table 5. *Cont.*

Tributaries of the Kharaa River (Kharaa River Tributaries = Kh_Trib)			
Kh_Trib_3	WB Khentii modified	Water body group (WBG) of the rhitral tributaries from the Khentii Mts. with anthropogenic impacts. orographic left (Gatsuurt Gol, sub-basin 4) and right (Shivertin Gol. sub-basin 8) of Kharaa river main course	4, 8
	221 km	Epi-. Metarhithral	
Kh_Trib_4	Boroo	Boroo Gol	6
	187 km	Hyporhithral	
Kh_Trib_5	Zagdalin Upper reaches	Zagdalin Gol upstream of the Zagdalin-Infiltration (subsurface flow of Zagdalin Gol)	7
	230 km	Epi-. Metarhithral. transition of Hyporhithral	
Kh_Trib_6	Zagdalin Lower reaches	Zagdalin Gol downstream of the Zagdalin-Infiltration (subsurface flow)	7
	22 km	Hyporhithral	
Kh_Trib_7	Bayangol	Bayangol	9
	103 km	Hyporhithral with transition to Epipotamal	
Total	1637 km	Total length of all tributaries to Kharaa	

Table 6. Length of river network per subbasin (Figure 2).

Sub-Basin	Name	River Length per Sub-Basin (km) Total Length	Main River	Tributary
1	Mandalin Gol	281.1	**-**	281.1
2	Bayangol I	103.7	-	103.7
3	Sugnugr Gol	166.6	-	166.6
4	Kharaa I	262.6	40.6	222.0
5	Tunkhelin Gol	148.3	-	148.3
6	Boroo Gol	186.7	-	186.7
7	Zagdalin Gol	255.0	-	255.0
8	Kharaa II	283.1	112.5	170.7
9	Bayangol	103.3	-	103.3
10	Kharaa III	160.1	160.1	-
Total		**1950.6**	**313.2**	**1637.4**
Total length of all water bodies			**1950.6 km**	
Length of water bodies (Kh_Trib_2) with reference state (percentage of water bodies in pristine conditions)			**583 km 30%**	

The stream reference condition represents the natural or near natural status of a water body with respect to biotic and abiotic factors. For water quality issues the Kh_Trib_2 water body group was used as the reference for the assessment as it represents a good ecological status (GES). Compared to the total length of all surface water bodies (1950.6 km), it can be stated, that around 30% (583 km) are in pristine condition. However, different colonization patterns of flora and fauna in several water bodies demanded adjustments to the reference conditions with expert knowledge during the biological assessment.

3.3. Observed and Monitored Pollution Patterns of Surface Waters in the KRB

The KRB is characterized by a relatively low population density (8 to 10 people km²). However, spatial concentrations of population in urban settlements, an often poor state of municipal wastewater infrastructures, and high livestock densities in the riverine floodplains as well as both small and large-scale mining activities all contribute to the potential threats facing the aquatic ecosystems of the KRB. In our study, the identified key stressors affecting water quality and the aquatic ecosystem of the KRB were: (i) rising nutrient inputs; (ii) high fine sediment loads; and (iii) mining-related influxes of toxic substances [14]. Even though most rivers in Mongolia are in relatively pristine condition, a state inventory for surface water conducted in 2003 displayed that at least 23 rivers in eight provinces were morphologically changed and/or polluted due to mining activities [63], including the Kharaa-Orkhon-Selenge river system.

In recent years, the uncontrolled expansion of mining activities have continuously and/or accidentally released toxic substances into the environment causing irreversible damage [64,65]. Studies in adjoining river basins have shown that gold, copper and molybdenum mining are major polluters [23,24,65,66], drastically affecting the ecology of diatom, macroinvertebrate and fish communities [39,64]. For example, in 2007, an accident at an illegal gold mine in Khongor Sum (Darkhan-Uul Aimag) contaminated groundwater and soil with mercury, zinc and cyanide, leaving far-reaching consequences for residents and their livestock due to increased exposure of contaminated water [40,67,68]. Even though no impact on near-by surface waters was documented, elevated levels of heavy metals, particularly arsenic and mercury, were detected in mining ponds, the Kharaa River main channel, and its tributaries below the mining site. A longitudinal profile of arsenic concentrations in surface waters of the KRB clearly shows evidence of geogenic levels in the Khentii Mountains (including Sugnugr and Kh_Trib_2), as well as distinctly elevated concentrations downstream of gold mines, in the middle and lower reaches of the KRB (Figure 5).

Moreover, elevated levels of arsenic were found in the ash basins of the thermal power plant adjacent to Darkhan city [21,26,41]. Considering the relevant discharge data, the mass transport of toxic metals, metalloids, chloride and boron as pollution indicators was estimated at the outlet of the KRB (Figure 6).

The high loads of Fe, Mn and Al associated with the geogenic background of the KRB, have likely resulted from the elevated levels of these elements occurring naturally in a large portion of the basins rocks. These elements have been released by natural weathering, and leaching processes due to the operation of chemical treatments in gold mines. As arsenic is commonly associated with gold-quartz veins, the leaching process often results in increased arsenic contamination of the surrounding environment.

In regards to the nutrient concentrations in the surface waters, there was both a clear longitudinal gradient across the KRB and an increasing temporal trend identified. Nitrogen and phosphorus concentrations increased significantly along the course of the Kharaa River from 0.4 to 0.6 $mg \cdot L^{-1}$ total N and 3 to 6 $\mu g \cdot L^{-1}$ of total P in the headwaters to 0.7 to 0.9 $mg \cdot L^{-1}$ total N and 54 to 154 $\mu g \cdot L^{-1}$ total P, respectively at the basin outlet (for total nitrogen (TN) see Figure 7). The highest concentrations were measured downstream of Darkhan's central wastewater treatment plant [15,18,21,35] with 1.5 $mg \cdot L^{-1}$ total N. The loads of orthophosphate-P at the basin outlet (Buren Tolgoi gauge) were increasing between 2007 and 2012 from 33 to 57 $t \cdot yr^{-1}$ due to increased emissions (Figure 8).

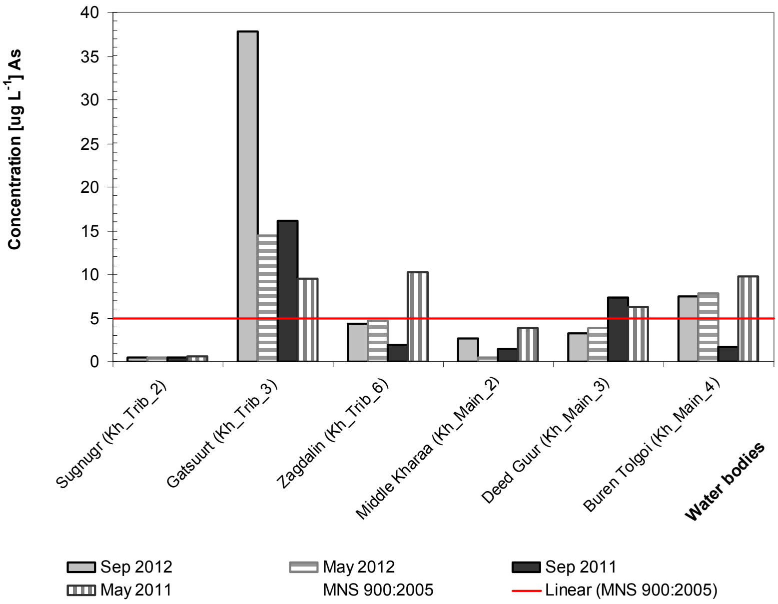

Figure 5. Concentrations of arsenic ($\mu g \cdot L^{-1}$) in a longitudinal profile from the Khentii Mountains. (Sugnugr Gol, natural reference conditions) to the river basin outlet at Buren Tolgoi based on four "snapshot" sampling campaigns of surface water in May and September 2011 and 2012 (21 May 2011, 06 September 2011, 18 May 2012, 9 September 2012). The allocation of sampling sites is indicated by the code number of the individual water bodies (Table 5, Figure 3). In comparison, the acceptable maximum content of arsenic according to the Mongolian drinking water quality standards (MNS (Mongolian National Standards) 900:2005) [69] is given as a horizontal line (Monitoring data of MoMo project).

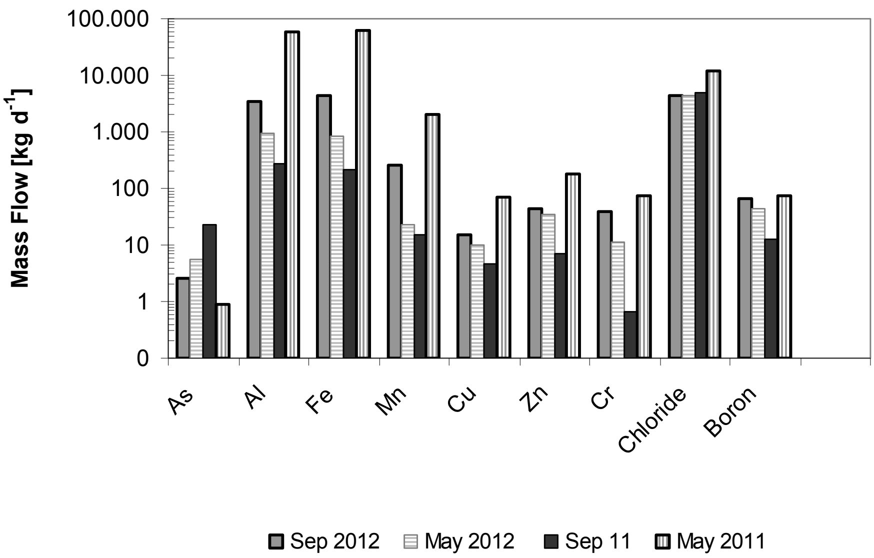

Figure 6. Mass flows ($kg \cdot d^{-1}$) of heavy metals, metalloids (As, Al, Fe, Mn, Cu, Zn, Cr) and pollution indicators (Chloride and Boron) at Buren Tolgoi close to the KRB outlet (Lower Kharaa Kh_Main_4, Sel_Kh10_001) based on four "snapshot" sampling campaigns in May and September 2011 and 2012 (21 May 2011, 06 September 2011, 18 May 2012, 9 September 2012). For exact locations of the water body and sampling site refer to Figure 3, Tables 1 and 5. (Monitoring data of MoMo project).

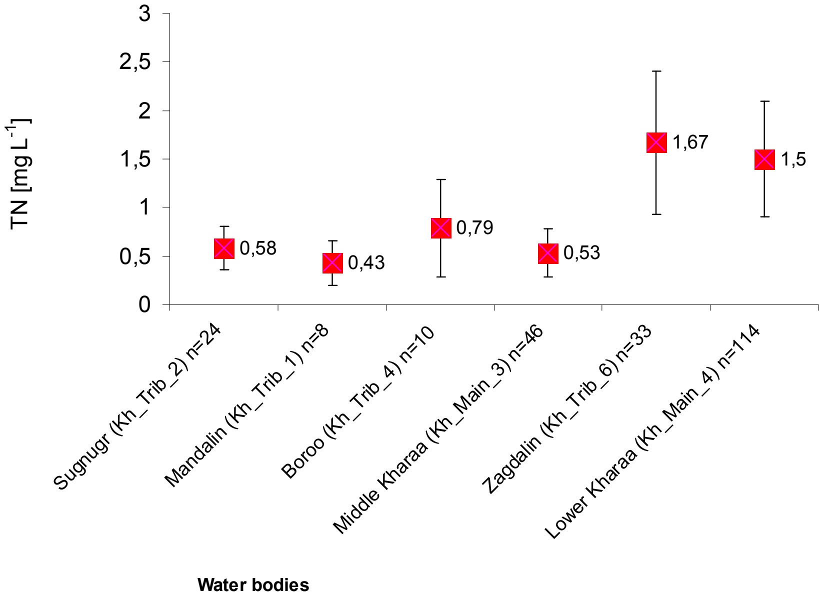

Figure 7. Concentrations of total nitrogen (TN) (mg·L^{-1}) in a longitudinal profile from the Khentii Mountains (Sugnugr, Kh_Trib_2, natural reference conditions) to the KRB outlet (Kh_Main_4) between 2007 and 2012. For each water body the number of analyzed water samples is indicated (*n*). For exact locations of the water body and sampling sites, see Figure 3, Tables 1 and 5. (Monitoring data of MoMo project).

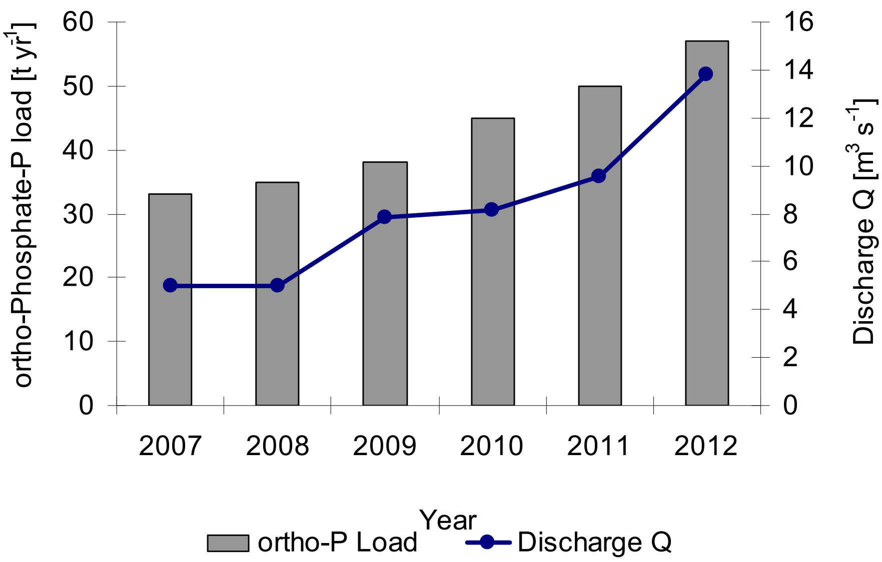

Figure 8. Loads of ortho-phosphate (t·yr^{-1}) at the KRB outlet (Lower Kharaa, Kh_Main_4, Sel_Kh10_001) for the monitoring period 2007 to 2012. The exact location of the water body and monitoring site Buren Tolgoi is given in Figure 3, Tables 1 and 5. (Monitoring data of MoMo project).

The observed total nitrogen loads in the KRB illustrate a substantial increase from 240 to 470 t TN·yr^{-1} indicating an increase of nutrients entering the river from diffuse sources [18].

Modeling results of nutrient emissions confirmed urban settlements as the main source of nitrogen and phosphorus emissions, contributing 55% (nitrogen) and 52% (phosphorus) of the total emissions of each nutrient [15]. As only 35% of the total population in the river basin is connected to a WWTP, unconnected urban areas represent a key proportion of the total emissions (38% of phosphorus and 25% of nitrogen emissions). In addition, the WWTP of Darkhan City with around 40,000 connected inhabitants was a substantial point source for nutrient influxes into the basin surface waters due to inefficient operations. According to additional modeling results, agriculture contributes 35% of total nitrogen and 32% of total phosphorus emissions [21], mostly through erosion from cultivated land and fallows. Moreover, sediment input caused by river bank erosion is a significant emission pathway for phosphorus [31,42].

High loads of fine sediment do not only act as a carrier of nutrients, but also constitute a major stressor themselves as sediment-induced clogging inhibits essential habitat functions of the hyporheic zones [31,32,70]. As a consequence, functional shifts of the macroinvertebrate community and fish fauna have already been observed [15,64]. Fine sediments are closely linked to the suspended transport of heavy metals, which is more extensive than the dissolved transport phase in the Selenge River basin [24]. Isotope-based sediment source fingerprinting techniques identified riverbank erosion (74.5%) and surface upland erosion (21.7%) as the main contributors to the suspended fine sediment load (grain size <10 μm) in the catchment [31,42]. Considering that only 20% to 35% of the river bank contains riparian vegetation in the lower catchment, there is only a limited capacity to restrain eroded sediments from entering the streams. Hence, erosion abatement is considered being a major management challenge in the KRB [35]. In the future, erosion could potentially increase more than twofold in the steppe regions of the lower KRB and up to sevenfold in the forested and mountainous regions of the upper KRB due to the combined impacts of land-use and climate change [71].

3.4. Water Quality and Ecological Assessment of Surface Water Bodies

The previously described water quality assessment applied in Mongolia, was based on a comparison of monitoring data for chemical substances, physical parameters and MNS (4586) [69,72,73]. The derived surface water quality index (WQI) is defined as a simple expression of a more or less complex combination of several parameters (e.g., NO_3–N, or TP), which serves as a measure for water quality [74]. This method is used to assess the ecological state of surface waters in Mongolia, which is then classified into six classes, ranging from "very good" (WQI < 0.3) to extremely polluted (WQI > 6.0). However, considering the maximum tolerable concentrations of chemical substances in MNS 4586 [72] are not derived from sound biological assessments, in relation to the impact of a given concentration to the ecological situation in a water body (e.g., TP concentration *vs.* Chlorophyll a concentration as expression of phytoplankton biomass), these concentrations describe more or less the threshold with an increased risk of impact to human health for a given exposure time.

Following the philosophy of the EC-WFD [50], it was proposed to identify reference conditions for undisturbed aquatic ecosystems which should be used to set standards for restoration goals. Thus a reference system with its concentration of chemical substances, its ecological state and the resulting ecological potential, represents a scientifically sound basis for the assessment of the water quality status. Impacted water bodies can then be described by *n*-fold increases of natural background conditions (except for pH and oxygen). In addition, the data logger measurements of pH- and oxygen amplitudes can be used as qualitative indication of eutrophication signals. The characterization of natural reference conditions was based on the Refcond Guidance [55,56] where the natural physical-chemical reference conditions of water bodies have been described with different anthropogenic indicators. These conditions were identified in the water body Kh_Trib_2 (Khentii Reference), thus representing the natural background conditions of nutrients and pollution indicators (chloride, boron and electrical conductivity; Table 7).

Table 7. Physico-chemical reference natural background conditions for the waterbody Kh_Trib_2 (Khentii reference) in comparison to the maximum tolerable concentrations of the Mongolian National Standards (MNS 900:2005, MNS 4586:1998) [69,72].

Parameter	**Mongolian Drinking Water Quality Standard MNS 900:2005**	**Mongolian Water Quality Standard MNS 4586:1998**	**Reference Conditions (Absence of Geogenic/ Anthropogenic Pollution**	
			Arithmetic Mean	Standard Deviation
Electrical conductivity ($\mu S \cdot cm^{-1}$)	n.i.	n.i.	49	10
Oxygen, dissolved (%)	n.i.	90	100	10
Oxygen ($mg \cdot L^{-1}$)	n.i.	>9	10.5	2.9
pH	n.i.	6.5–8.0	7	0.4
Boron ($\mu g \cdot L^{-1}$)	500	n.i.	10	12
Chloride ($mg \cdot L^{-1}$)	350	<50	2	0.5
TP ($\mu g \cdot L^{-1}$)	n.i.	<25	11	10
SRP ($\mu g \cdot L^{-1}$)	n.i.	<20	5	1
TN ($mg \cdot L^{-1}$)	n.i.	<0.3	0.58	0.22
NH_4–N ($mg \cdot L^{-1}$)	1.5	<0.02	0.02	0.01
NO_3–N ($mg \cdot L^{-1}$)	1	<1	0.3	0.2
As ($\mu g \cdot L^{-1}$)	10	n.d.	1.8	1
Hg ($\mu g \cdot L^{-1}$)	0.5	n.d.	n.d.	n.d.

Notes: n.i. = no information; n.d. = not detectable, below detection limit.

While the natural reference concentrations for chloride (2 $mg \cdot L^{-1}$ Cl) and boron (10 $\mu g \cdot L^{-1}$ B) ($n = 25$ for Cl and B) in upstream water body group Kh_Trib_2 (Khentii reference) were close to or below the analytical detection range, the anthropogenic altered concentrations in the downstream water bodies Kh_Main_1 to Kh_Main_4 exceeded the natural background by a factor of 4 (boron 38 $\mu g \cdot L^{-1}$) and 6 (chloride 12 $mg \cdot L^{-1}$) [68].

The comparison of the three data logger stations clearly shows a gradient from the upstream regions to the middle and lower reaches in the KRB (Table 8, Supplementary Material S.2.).

The water level measurements from the three monitoring stations along the Kharaa River (Supplementary Material S.2., Figure S1a) exhibited a natural flooding regime including flood pulses and broadened flood peaks in the downstream direction (Sugnugr >> Baruunkharaa >> Buren Tolgoi). The gauging stations clearly reflected the increased intensity in rainfall events during the spring and summer periods resulting in prolonged flooding events during the summer months in the downstream regions (Buren Tolgoi).

Table 8. Physical and chemical measurements (mean ± SD) of the automatic water quality monitoring stations at Sugnugr (Khentii reference Kh_Trib_2), Baruunkharaa (Middle/Lower Kharaa. Kh_Main_3) and Buren Tolgoi (Lower Kharaa. Kh_Main_4) for the vegetation period (May to October) in 2012. For allocation of primary code ID of stations see Table 1.

Station Primary Code ID	**Sugnugr Sel_Kh03_009**	**Baruunkhaara Sel_Kh10_012**	**Buren Tolgoi Sel_Kh10_001**
Temperature (°C)	7.1 ± 3.9	12.9 ± 5.3	14.8 ± 6.2
Conductivity ($\mu S \cdot cm^{-1}$)	41.7 ± 6.6	250.8 ± 63.6	250.3 ± 63.6
pH	7.19 ± 0.26	8.1 ± 0.2	8.36 ± 0.12
Oxygen saturation (%) *	99.8 ± 3.1	95.0 ± 9.5	98.6 ± 4.7 *
Oxygen concentration ($mg \cdot L^{-1}$) *	10.6 ± 1.2	9.3 ± 1.4	8.9 ± 1.1 *

Note: * Oxygen measurements at station Buren Tolgoi were conducted only until mid of September 2012.

The water temperature regime of the Kharaa River was recorded during the ice free period and was predominantly shaped by strong seasonal and diurnal temperature fluctuations caused by the continental climatic conditions (Supplementary Material S.2., Figure S1b). The increased temperature at the middle and downstream stations of Baruunkharaa and Buren Tolgoi, in comparison to the upstream station (Sugnugr), was most likely caused by lower flow velocities during the summer months where increased channel width and low shading effects triggered by fragmentary riparian vegetation in these reaches increased the water temperature.

The electrical conductivity (EC) recorded in the upper region of the Kharaa River was very low, mostly below 50 $\mu S \cdot cm^{-1}$, which further highlights the pristine water quality conditions of the upper basin (Supplementary Material S.2., Figure S1c). The EC measurements were elevated in the middle basin at Baruunkharaa station where the associated flood events caused fine sediments to be (re-) mobilized from river substrate and river banks. On the contrary, EC measurements at the lower monitoring station were decreasing during flooding events, which may be interpreted as a simple dilution effect due to more stable river morphology in this downstream area.

Considering the dependency of dissolved oxygen on water temperature, lower oxygen concentrations in the middle and the downstream regions of the KRB were expected (Supplementary Material S.2., Figure S2a). However, an increased oxygen saturation in the mid catchment station, and to a lesser extent at the downstream station, especially under low flow situations, may indicate a potentially enhanced eutrophication risk in these areas, as an increase in photosynthesis and primary production is evident (Supplementary Material S.2., Figure S2b).

In the present study, a human health perspective involving the investigation of faecal indicators and its bacteriological status were not included in the monitoring schemes. The pivotal question for the future will be whether these parameters provide essential and additional information about the river's status and its quality.

Stream biological quality indicators including the benthic invertebrate community and fish fauna investigations suggested a "good" ecological status for most river stretches in the Kharaa River basin (Tables 9 and 10). Nevertheless, the structural and functional metrics of the benthic invertebrate community indicated negative impacts in certain parts of the catchment, especially in the middle reaches of the Kharaa River main channel (water bodies Kh_Main_2 und Kh_Main_3, Figure 4), but also in certain tributaries (water bodies Kh_Trib_1, Kh_Trib_4 und Kh_Trib_6, see Table 9).

Table 9. The ecological assessment of the Kharaa River, using the benthic invertebrate community. The table shows ecological quality metrics on a five step scale with 1 being "very good" and 5 being "bad" (EQ = Ecological quality. E = Ephemeroptera = mayflies. P = Plecoptera = stoneflies. T = Trichoptera = caddisflies).

Water Body/Sampling Site	EQ of Site	EQ of Water Body	Total Number of Species	Number of P	Number of E	Shannon Diversity Index	Share of EPT Individuals	Share of Fine Sediment Colonizers
Kharaa River main course								
Kh_Main_1		2						
Kh_8.5	2		1	2	2	2	1	2
Kh_8.3	2		1	2	3	1	1	2
Kh_8	2		1	1	2	2	1	2
Kh_Main_2		3						
Kh_7	2		2	1	2	2	2	2
Kh_6	3		2	3	2	2	3	3
Kh_5	2		2	2	2	3	3	2
Kh_4	3		2	2	3	3	2	2
Kh_3.5	3		3	3	2	2	2	3
Kh_Main_3		3						
Kh_3	3		3		3	4	4	2
Kh_Main_4		3						
Kh_2	3		3		3	3	3	1
Kh_1	2		3		3	2	1	2
Kharaa River tributaries								
Kh_Trib_1		3						
Mand_1	3		2	5	4	3	5	1
Mand_2	3		1	4	3	3	5	1
Kh_Trib_2		2						
Sug_2	2		1	1	3	2	3	2
Sug_1	2		2	1	3	2	3	2
Baya_1	2		1	2	3	1	1	1
Tun_1	2		2	1	3	2	2	2
Kh_Trib_3		2						
Shiv_1	2		1	3	3	1	1	1
Kh_Trib_4		3						
Bor_0.5	3		1	4	4	3	5	1
Kh_Trib_5								
Zagdalin upstream	no data							
Kh_Trib_6		4						
Zag_1	4		3	5	5	3	4	2
Kh_Trib_7								
Bayangol2	no data							

Table 10. The ecological assessment of fish fauna along sample sites in the KRB. The table shows the ecological quality metrics on a five step scale with 5 being "very good" and 1 being "bad". Note that the evaluation scale (5–1) of Table 10 are inverted compared to the

evaluation scale (1–5) of Table 9 due to the applied FIBS tool [59] ("species and ecological guilds" = occurrence of river type specific species, accompanying species, migratory species, habitat guilds, reproductive guilds and trophic guilds; "abundances and ecological guilds" = relative abundance of dominant species, relative abundances of perch/roach, distribution of ecological guilds; "age structure" = relative share of 0+ species).

Water Body/Sampling Site	EQ of Site	EQ of Water Body	Species and Ecological Guilds	Abundances and Ecological Guilds	Age Structure	Migratory Index	Fish Region	Community Dominance Index
Kharaa River main course								
Kh_Main_1		3						
Kh_8.5	3.13		2.67	2.67	4.2	3	5	1
Kh_8	2.65		2	2.33	4.6	1	3	1
Kh_Main_2		3						
Kh_7	3.13		2.33	3	4.2	1	5	3
Kh_6	2.84		3	1.83	4.2	1	5	1
Kh_5	2.93		3.1	2.5	3	2	5	2
Kh_4	3.02		3	2.91	3.2	2	5	2
Kh_Main_3		2						
Kh_3	2.15		2.67	2.6	1.67	1	3	1
Kh_Main_4		3						
Kh_2	3.40		3.67	2.6	5	1	3	3
Kh_1	2.81		3	2.5	3.33	3	4	1
Kharaa River tributaries								
Kh_Trib_1		2						
Mand_1	3.06		4	1.91	4	1	5	1
Mand_2	2.30		2.33	1.55	3	1	5	1
Kh_Trib_2		3						
Sug_2	2.66		3	1.8	1.5	5	5	3
Sug_1	3.31		3.84	2.5	3.5	3	5	2
Baya_1	2.91		3.5	1.8	4	1	5	1
Tun_1	4.02		3.67	3.4	4	5	5	5
Kh_Trib_3		3						
Shiv_1	2.72		2.67	1.55	3	5	5	1
Kh_Trib_4		3						
Bor_0.5	3.55		3.67	3.55	4	1	5	3
Kh_Trib_5								
Zagdalin upstream		no data						
Kh_Trib_6		3						
Zag_1	3.31		4	2.09	3.5	1	5	5
Kh_Trib_7								
Bayangol2		no data						

The vertical exchange of water between the river and hyporheic zone was measured by Hartwig [31,32], who found evidence for the physical clogging of the river bed in some stretches of the Kharaa River downstream from the confluence with the Zagdalin River. The physical clogging of the river bed may reduce habitat quality for benthic invertebrate species having life stages that are associated with the hyporheic zone as well as for gravel spawning fish. Analyses of the river fish fauna composition illustrated a reduced number of those species that are targeted or regularly caught by resident fishers. The taimen (*Hucho taimen*), an endangered salmonid, is once such species, which is all but locally extinct in the basin and is continually facing rapid population declines across all Mongolia due to increased poaching activities. Additionally, a relative reduction of larger individuals of several fish species (e.g., *B. lenok* and *T. baicalensis*) was also identified (see Table 10).

In order to successfully maintain healthy fish stocks throughout the KRB, better compliance and stricter enforcement of Mongolia's existing fishing regulations is vital. It is essential that illegal fishers are detected and prosecuted for their use of prohibited and damaging fishing gear (e.g., nets, dynamite, or triple hooks), for fishing during spring spawning closed seasons (1st of April until the 15th of June every year), and for the intentional killing of protected species. In addition, further enhancements to the fishing legislation such as minimum sizes and total take limits should also be introduced to mitigate overfishing practices and better protect these threatened fish communities and the ecological health of the river for the future. A recent survey among fishers in the KRB conducted in 2012, highlighted the fact that many local fishers could not identify fish species correctly nor were many aware of the existing regulations (Andrew Kaus, unpublished data 2012). Therefore, widespread educational campaigns and capacity development activities are urgently required to improve fisher knowledge, understanding and compliance in the Kharaa River basin.

The ecological quality of surface waters in the upstream reaches of the KRB (water body Kh_Main_1), as indicated by benthic invertebrate assessments, was classified as "very good" or "good" between 2006 and 2011. Benthic invertebrate communities were highly diverse and represented a more or less natural reference condition. The fish-based assessment using FIBS also indicated a "good" ecological condition between 2006 and 2012, denoting an un-impacted and healthy river. Human activities in these regions only moderately affected fish species richness, relative abundances and diversity of fish species.

In the middle reaches of the Kharaa River (water body Kh_Main_2) a "good" to "moderate" ecological status was determined from the assessment of benthic invertebrates, with deficits identified in the structural composition of the community especially in the lower sections. The fish community composition in the mid Kharaa River catchment indicated in general a "good ecological status" for the years 2006 to 2012. Some minor deficits were identified with regards to species abundance and the distribution of age classes and indicator indices. These deficits were attributed to increased fishing pressure in the region over recent decades. Furthermore, the assessment shifted from "good" to "moderate" between 2006 and 2012.

The middle and lower reaches of the Kharaa River (water body Kh_Main_3) were assessed in 2006 and 2007 at a single location, with structural and functional deficits in the benthic invertebrate communities identified, which in turn resulted in a "moderate" ecological status classification. The assessment of resident fish communities also suggested a "moderate" ecological status, although with similar deficits as described for water body Kh_Main_2. However, it must be noted that only one sampling site could be analyzed for this section of the river.

The lower reaches of the Kharaa River (water body Kh_Main_4), from close to the city of Darkhan until the confluence with the Orkhon River were assessed as being at a "good" or "moderate" ecological status. Some minor effects on ecological quality downstream from Darkhan were identified, but 20 km further downstream, close to the hydrological measuring station "Buren Tolgoi", these deficits were no longer observed. The unknown reference conditions for this stream type (Mid-sized and large lowland rivers dominated by sand and loam) impeded the ecological assessment which therefore was based on the creation of a reference biocoenosis with expert knowledge. The fish-based assessment indicated a "good" ecological status with some minor deficits in species abundance and the distribution of ecological guilds. The total density of individual fish was relatively low in the Kharaa River lower reaches, which may have been caused by increased fishing pressure in the region, but is also likely due to the relatively low species diversity in this river section.

The tributaries in the southernmost part of the catchment (Mandalin Gol, water body Kh_Trib_1), are characterized by a gradually declination, ground slope (around 2 per mill) with pasture farming close to the rivers. The ecological quality as indicated from macroinvertebrate assessment, during 2006/2007, was "moderate" to "poor". By contrast, fish assemblages indicated a "moderate" ecological quality with deficits in abundance and guild distributions.

The tributaries originating in the Khentii Mountains (water bodies Kh_Trib_2) were identified as being in a natural reference state with regards to benthic invertebrates, and could be classified from 2006 to 2011 as "very good" to "good" with some seasonal variability. The fish community surveys also indicated a "very good" to "good" ecological quality of these river sections, although showed some minor restraints in age and abundance structures, as the number of species caught were slightly reduced.

Tributaries representing lower mountainous streams originating in the forelands (Shivertin Gol, water bodies Kh_Trib_3), showed a "good" ecological status based on both benthic invertebrates and fish surveys. The small stream Gatsuurtin Gol was not assessed during the sampling period.

The initial assessment of the Boroo Gol (water body Kh_Trib_4) indicated a "moderate" ecological status, with the number of EPT species strongly reduced in the benthic invertebrate samples. An increased share of potamophilous and lotic species was identified, which may have been caused by an altered hydrological regime. Additionally, green filamentous and blue-green algae were observed during the samplings, also indicating altered hydrology and increased nutrient concentrations. Nonetheless, the fish fauna assessment indicated a "good" ecological status in the Boroo River.

The lower reaches of the Zagdalin River sub-catchment (water body Kh_Trib_6), a major tributary of the Kharaa River, was assessed as being in a "moderate" or "poor" ecological status. A considerable reduction in the number of EPT species was determined, with the total number of species and individuals being also relatively low resulting in a low biodiversity index (Table 10). In contrast to these findings, the fish fauna showed only minor ecological deficits with regard to species richness and in the structure and abundances of ecological guilds.

In the water bodies of the upper Zagdalin Gol sections, (water body Kh_Trib_5) and Bayangol II (water body Kh_Trib_7), there was no ecological assessment performed.

3.5. Initial Risk Assessment of Surface Water Bodies in the KRB

The results of the initial risk assessment for the surface water bodies in the KRB, following the methods detailed in Section 2.5, have been visualized below in Figure 9. Water bodies with a higher risk of failing to reach a "good" chemical status were mostly situated in the mid and lower reaches of the KRB marked in red and yellow.

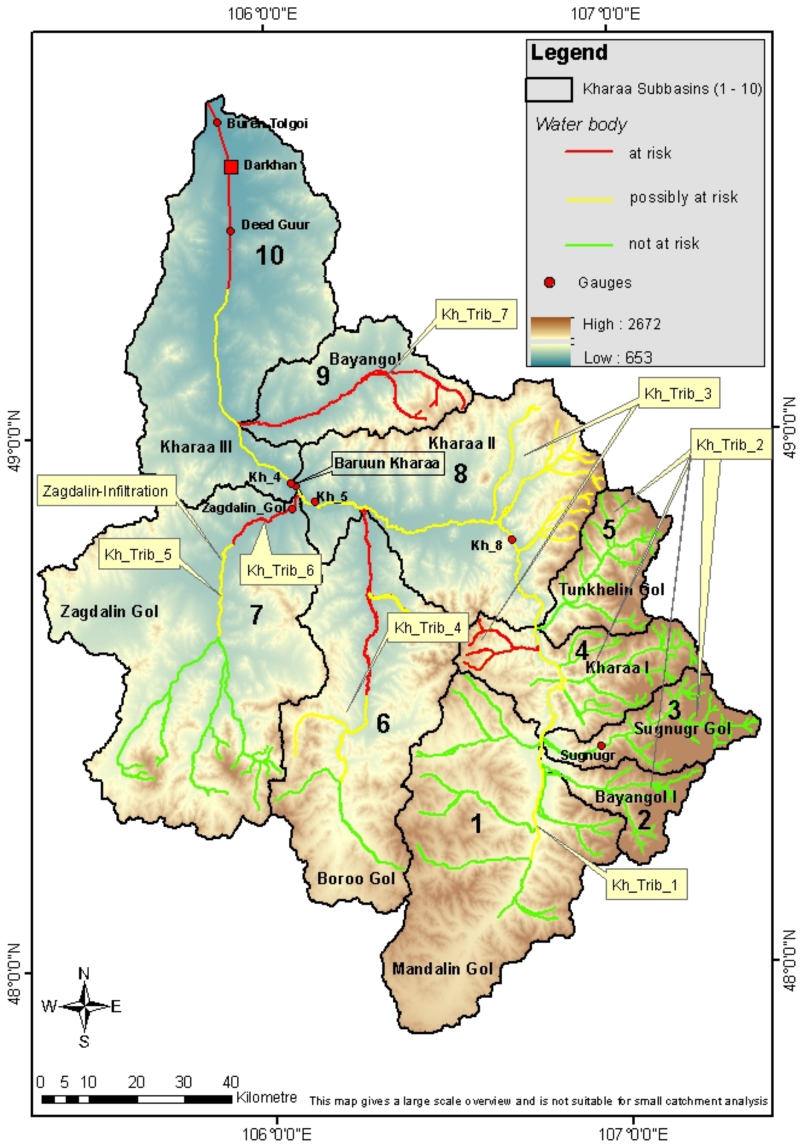

Figure 9. Initial assessment of the KRB surface water bodies, indicating the risk of failure to reach a good chemical and/or ecological status. In addition to the presented assessment with the illustrated surface water monitoring sites, the map considers data derived from other publications [13,22,25,41,65].

The detailed evaluation matrix of each individual water body concerning the initial risk assessment is given in Supplementary Material S.3. Compared to EC-WFD based ecological status classifications of river basins in Central Europe with significant higher data availability [75] the presented risk assessment in the KRB can initially serve as a basis for the future sustainable management of natural water resources.

In contrast to the findings presented here, the most recent Mongolian report on water quality in the KRB (Zandaryaa) [13] states that the "*overall assessment of the chemical composition has shown good chemical conditions at the sampling sites in the Kharaa River, and there was no clear indication of nutrient pollution. Moreover, the heavy metal contamination study was only assessed with concentration of iron and chromium (VI) and the concentrations did not exceed the regulatory limits. The hydrobiological assessment based on the macroinvertebrate community within the framework of the surface water quality monitoring program in the KRB has been conducted since 2005. The analysis of the results from two monitoring sites between 2005 and 2010 indicated a good ecological status for the river*" (Zandaryaa) [13]. This statement is based on five monitoring stations throughout the Kharaa River main channel (Table 1), using the Kharaa station upstream of Zuunkharaa (Sel_Kh08_004 in Table 1) as a reference site. However, the Kharaa River station upstream of Zuunkharaa does not present pristine conditions since there are several "hot spots" (e.g., gold mining in the Gatsuurtin tributary area) upstream of this station. Thus, the methods of water quality assessment (Section 3.4) and the resulting differences underline the necessity to reconsider/reinterpret the results of Zandaryaa [13] in the light of the current results.

3.6. Stressor Complexes and Need for Action at the River Basin Level

Environmental changes that cause certain responses in a system of interest (e.g., an ecosystem) can be described as a stressor [76]. Direct stressors can represent the immediate cause of an effect (e.g., oxygen depletion causing suffocation of fish), while indirect stressors are preceding factors, in a causal pathway conditioning an effect (e.g., river bank erosion-causing clogging of the hyporheic zone- in turn creating a response in the invertebrate community). After incorporating and evaluating all available data concerning the KRB, eight thematic stressor complexes for the water management sector were identified:

- Insufficient provisions of safe drinking water and hygienic sanitation in ger populations (low income, peripheral settlements consisting of traditional Mongolian felt tents (ger) and/or simple, detached houses) [77];
- Deficient water supply and wastewater disposal systems for rural settlements [77];
- Degradation of hydrological processes in the Khentii Mountains, that are essential for the recharge of surface and groundwater resources of the entire basin [17,34,35];
- Unregulated mining activities impacting the quality and quantity of the already scarce surface water resources [26,40,41];
- Erosion of the cleared and structurally fragile river banks and the resulting high fine-grained sediment loads that are inhibiting habitat functions on the river substrate [31,32].

In general, the density of the monitoring network in the KRB for biological and chemical water quality indicators is not very high and in some regions completely lacking, so that a comprehensive assessment and stressor identification is often not possible.

Prioritizing actions is necessary in order to secure ecosystem services and sustainable utilization of water resources in the KRB. The nexus of deficits, causes and countermeasures as well as the identified stressor complexes provide an essential overview (Supplementary Material S.4., Tables S12 and S13). The need for protection of environmental assets can be ranked as follows:

(i) The first critical measure must involve the conservation of the KRB's "water towers", which includes all tributaries originating from the Khentii mountains, (especially water body group Kh_Trib_2) in order to safeguard the current amount of surface water quantity [17,78] and quality [15]. In addition, the mountainous water courses represent important places of reproduction, feeding and refuge for the aquatic fauna. Thus, these areas must be exempted from any exploitation, especially from mining, deforestation, overgrazing and overfishing.

(ii) The regeneration of river riparian zones must be fostered by eliminating/reducing the major pressures (e.g., livestock herding). Protecting non-degraded, remnant river riparian zones as well as areas with a high potential of self-regeneration should have the highest priority [32].

(iii) The infiltration of untreated wastewater into groundwater which is then extracted for domestic self-supply in the river riparian zones must be first identified and subsequently measures implemented to abate this practice. The installation of adapted semi-central wastewater collection and treatment technologies in combination with timber production is one option that would minimize the pressure on riparian vegetation [77].

(iv) Measures must be taken to avoid contamination from mining operations, while at the same time implementing rehabilitation measures of insecure tailing basins, such as the ash deposition sites of the thermal power plant in Darkhan.

With respect to water quality, the most relevant problems include erosion and the subsequent high fine sediment loads, the poor state of wastewater infrastructures, and the emission of toxic substances related to mining and industrial activities (Supplementary Material S.4.). Grazing pressure due to large numbers of livestock contributes to the destabilization of riverbanks, thus promoting their erosion and the influx of high fine sediment loads. Strategies to prevent river bank erosion therefore must include viable alternatives for animal grazing such as the installation of protected buffer strips and the provision of alternative drinking water sources for animals [31]. Moreover, land management practices which are better suited to the semi-arid steppe environment (e.g., mulching of croplands with wheat straw), if employed in the future could additionally help to reduce soil erosion [71].

With regard to the emission of toxic substances, a stricter enforcement of existing environmental legislation is crucial. In the recent past, water governance in Mongolia was characterized by unclear and/or overlapping competences of a wide range of institutions, limited budgets for environmental monitoring and implementing of conservation measures, as well as a lack of water experts, especially in rural areas. However, there have been substantial reforms in recent years, including the promotion of IWRM/RBM as the national strategy for sustainable management [79–85]. In the KRB, water contamination by heavy metals is typically linked to either gold mining or industrial activities including power generation. While mining activities have become more regulated in the past few years (including provisions to ban mining within 50 m from river banks), there is still a lack of emission control. Moreover, long lasting legacies of past emissions have led to the contamination of sediments from where toxic substances remain and continue to be released. For the KRB, unlike many other river basins of Mongolia, these hot spots of environmental contamination are documented [15,18,21], allowing for a more systematic surveillance and planning of rehabilitation measures. A summary of the recommended measures is given in Supplementary Material S.5., Tables S14 to S23.

4. Conclusions

In this paper, the presented concept of characterizing stream landscapes in northern Mongolia and delineating water bodies as water management units serves the purpose of reporting and designing river basin management plans. Using the criteria of the German river typology as a framework and taking ecoregion features into account like geology, geomorphology, vegetation and climate, five different river types were distinguished in the KRB: (i) Small siliceous highland rivers dominated by coarse substrate; (ii) Small siliceous highland rivers dominated by fine substrate; (iii) Large gravel rich highland rivers; (iv) Small lowland rivers dominated by sand; and (v) Mid-sized and large lowland rivers dominated by sand and loam. Subsequently, we divided the Kharaa River main channel into four water bodies and its tributaries into seven water bodies, with comparable biocoenotical, physical-chemical and hydrological features. This approach was regarded as useful for water resources assessments and the identification of management measures.

The Khentii Mountains in the north-east of the catchment were found to be the "water towers" of the basin and represent an undisturbed reference state without anthropogenic impacts on aquatic ecosystems. Thus, these stream reaches with its characteristically low concentrations of chemical substances and its distinguishing biocoenosis and excellent ecological status, represent a reference location that can be regarded as a scientifically sound base for the assessment of the water quality status across the KRB. The assessment of anthropogenic impacts in comparable water bodies can then be described with the *n*-fold exceeding level from natural background concentrations and can be used to set standards for restoration. This approach offers the possibility to develop new assessment tools, having a sound scientific base compared to the application of actual national standards which are lacking any bio assessment philosophy.

The initial risk assessment of the ecological and chemical status of surface waters in the KRB revealed the following picture:

(i) Most water bodies in the upper reaches are in good chemical and ecological conditions;
(ii) The impact of gold-mining, urbanization, overgrazing, logging and wild fires have had a substantial impact on the water quality in the middle and lower reaches;
(iii) Downstream of the impacted reaches there is still a remarkable potential for nutrient retention and self-cleaning processes, which are threatened without implementing protection measures.

In conclusion, the interconnection of anthropogenic pressures, ecological deficits, causes and rehabilitation/protection measures should be assessed in detail on a water body scale, in order to foster the ongoing process of designing a catchment specific river basin management plan. The example of the KRB demonstrates that RBM planning and implementation in environmentally and socioeconomically heterogeneous river basins requires more homogenous sub- units for management actions. The presented delineation of water bodies, as is common practice in the context of the EU-WFD implementation, ideally serves this purpose.

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Author Contributions

Jürgen Hofmann, the first author, structured and drafted most parts and figures of the original manuscript and coordinated the work of the co-authors. Daniel Karthe drafted Sections 3.1 and 3.3 (pollution patterns of surface waters) and contributed to all sections dealing with water quality assessment (Sections 3.4 and 3.5). Ralf Ibisch and Michael Schäffer drafted Section 2.3 (biological data) and linked ecological assessments with findings on water quantity and quality (Sections 3.4 and 3.5). They also contributed to the Supplementary Materials S.1., S.3. and S.5. and helped formatting the manuscript. Michael Schäffer edited Supplementary Material S.2. Sonja Heldt contributed to Section 1.3 (water management in Mongolia), Section 3.6 (stressor complexes) and Supplementary Materials S.1., S.4. and S.5. Saulyegul Avlyush co-authored the sections dealing with water quality monitoring in KRB (Section 1.2), water management in Mongolia (Section 1.3) and translated the abstract and headings of all Tables and Figures into Mongolian language (Supplementary Material S.6.). Andrew Kaus thoroughly revised the entire manuscript and included biological information on Sections 2 and 3.

Supplementary Materials

Supplementary materials can be accessed at: http://www.mdpi.com/2073-4441/7/6//s1-6.

Conflicts of Interest

The authors declare no conflict of interest.

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