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Water Quality Issues in Rivers, Lakes and Reservoirs in Asian Countries – an Approach to the Problems and the Methodologies

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Abstract

Water covers over 70% of the Earth's surface, and is vital for all known forms of life. But only 3% of the Earth's water is fresh water, and less than 0.3% of all freshwater is in rivers, lakes, reservoirs and the atmosphere. However, rivers and lakes are an important part of fresh surface water, amounting to about 89%. In this Master Thesis dissertation, the focus is on three types of water bodies – rivers, lakes and reservoirs, and their water quality issues in Asian countries.

The surface water quality in a region is largely determined both by the natural processes such as climate or geographic conditions, and the anthropogenic influences such as industrial and agricultural activities or land use conversion.

The quality of the water can be affected by pollutants discharge from a specific point through a sewer pipe and also by extensive drainage from agriculture/urban areas and within basin. Hence, water pollutant sources can be divided into two categories: Point source pollution and Non-point source (NPS) pollution.

Seasonal variations in precipitation and surface run-off have a strong effect on river discharge and the concentration of pollutants in water bodies. For example, in the rainy season, heavy and persistent rain wash off the ground, the runoff flow increases and may contain various kinds of pollutants and, eventually, enters the water bodies. In some cases, especially in confined water bodies, the quality may be positive related with rainfall in the wet season, because this confined type of fresh water systems allows high dilution of pollutants, decreasing their possible impacts. During the dry season, the quality of water is largely related to industrialization and urbanization pollution.

The aim of this study is to identify the most common water quality problems in Asian countries and to enumerate and analyze the methodologies used for assessment of water quality conditions of both rivers and confined water bodies (lakes and reservoirs).

Based on the evaluation of a sample of 57 papers, dated between 2000 and 2012, it was found that over the past decade, the water quality of rivers, lakes, and reservoirs in developing countries is being degraded. Water pollution and destruction of aquatic ecosystems have caused massive damage to the functions and integrity of water resources. The most widespread NPS in Asian countries and those which have the greatest spatial impacts are urban runoff and agriculture. Locally, mine waste runoff and rice paddy are serious NPS problems. The most relevant point pollution sources are the effluents from factories, sewage treatment plant, and public or household facilities.

It was found that the most used methodology was unquestionably the monitoring activity, used in 49 of analyzed studies, accounting for 86%. Sometimes, data from historical databases were used as well. It can be seen that taking samples from the water body and then carry on laboratory work (chemical analyses) is important because it can give an understanding of the water quality. 6 papers (11%) used a method that combined monitoring data and modeling. 6 papers (11%) just applied a model to estimate the quality of water. Modeling is a useful resource when there is limited budget since some models are of

free download and use. In particular, several of used models come from the U.S.A, but they have their own purposes and features, meaning that a careful application of the models to other countries and a critical discussion of the results are crucial. 5 papers (9%) focus on a method combining monitoring data and statistical analysis. When there is a huge data matrix, the researchers need an efficient way of interpretation of the information which is provided by statistics. 3 papers (5%) used a method combining monitoring data, statistical analysis and modeling. These different methods are all valuable to evaluate the water quality.

It was also found that the evaluation of water quality was made as well by using other types of sampling different than water itself, and they also provide useful information to understand the condition of the water body. These additional monitoring activities are: Air sampling, sediment sampling, phytoplankton sampling and aquatic animal tissues sampling.

Despite considerable progress in developing and applying control regulations to point and NPS pollution, the pollution status of rivers, lakes, and reservoirs in Asian countries is not improving. In fact, this reflects the slow pace of investment in new infrastructure for pollution control and growing population pressures.

Water laws or regulations and public involvement in enforcement can play a constructive and indispensable role in environmental protection. In the near future, in order to protect water from further contamination, rapid action is highly needed to control the various kinds of effluents in one region. Environmental remediation and treatment of industrial effluent and municipal wastewaters is essential. It is also important to prevent the direct input of agricultural and mine site runoff. Finally, stricter environmental regulation for water quality is required to support protection and management strategies.

It would have been possible to get further information based in the 57 sample of papers. For instance, it would have been interesting to compare the level of concentrations of some pollutants in the different Asian countries. However the limit of three months duration for this study prevented further work to take place. In spite of this, the study objectives were achieved: the work provided an overview of the most relevant water quality problems in rivers, lakes and reservoirs in Asian countries, and also listed and analyzed the most common methodologies.

Resumo

A água cobre mais de 70% da superfície da Terra e é vital para todas as formas de vida conhecidas. Contudo, apenas 3% da água na Terra é doce e menos de 0.3% de toda a água doce encontra-se nos rios, lagos, albufeiras e na atmosfera. Apesar disso, os rios e os lagos são uma fração importante da água doce disponível à superfície, atingindo cerca de 89% dessa parcela. Esta dissertação de mestrado debruça-se sobre três tipos de massas de água em países asiáticos – rios, lagos e albufeiras – nos problemas associados à qualidade da água das mesmas e nas principais metodologias utilizadas nos estudos efetuados nos últimos 13 anos.

A qualidade da água de uma dada região é grandemente influenciada por processos naturais (tais como a precipitação e a erosão do solo), pela ação antropogénica, pelas atividades industriais e agrícolas e pela crescente exploração dos recursos hídricos.

A qualidade da água pode ser afetada pela descarga de poluentes num determinado ponto específico, como a descarga dum coletor de águas residuais, mas também pela drenagem de áreas de cultivo ou zonas urbanas localizadas na bacia hidrográfica. Assim, as fontes de poluição hídrica podem dividir-se em duas categorias: fontes pontuais e fontes difusas de poluição, sendo que a escala de análise espacial pode transformar fontes pontuais em difusas.

A qualidade da água é atualmente um assunto preocupante na Ásia, como no resto do mundo. O objetivo deste estudo é identificar quais os problemas mais comuns de qualidade da água em países asiáticos, bem como identificar e analisar as metodologias utilizadas na avaliação da qualidade da água, quer em rios, quer em massas de água confinadas (lagos e albufeiras).

As variações sazonais da precipitação e do escoamento superficial têm influência direta no caudal escoado nos rios e na concentração de poluentes nas massas de água. Por exemplo, na estação pluviosa, a precipitação intensa e persistente causa erosão do solo, o caudal escoado aumenta podendo incorporar diversos tipos de poluentes antes de encaminhar-se para as massas de água. Em alguns casos, particularmente de massas de água confinadas, a qualidade da água pode ter relação direta com a precipitação durante a estação pluviosa, pois as albufeiras permitem uma grande diluição de poluentes, diminuindo os seus impactos. Durante a estação seca, a qualidade da água é fortemente condicionada pela poluição de origem industrial e urbana.

Com base na avaliação de uma amostra de 57 publicações científicas, datadas entre 2000 e 2012, verificou-se que na última década a qualidade da água em rios, lagos e albufeiras de países em desenvolvimento está a degradar-se. A poluição da água e a destruição de ecossistemas aquáticos tem causado enormes danos nas funções e na integridade dos recursos hídricos. Em países asiáticos, as fontes de poluição difusas mais vulgares e com maior impacto espacial são as escorrências urbanas e a agricultura. Localmente, a lixiviação de explorações mineiras e de arrozais podem ser fontes importantes de poluição difusa. Por outro lado, as fontes mais relevantes de poluição pontual são os efluentes de indústrias, de estações de tratamento de águas residuais e os efluentes urbanos. Da análise realizada, pode afirmar-se que as causas principais para a degradação da qualidade da água em países asiáticos são a pressão demográfica

e a industrialização.

Nos artigos analisados verificou-se que a metodologia mais comum era, sem qualquer dúvida, a monitorização do meio hídrico, utilizada em 49 dos estudos analisados, respondendo por 86% dos casos. Os autores recorrem, por vezes, a registos históricos de bases de dados. Constatou-se que a recolha de amostras na massa de água e a posterior análise em laboratório (análise química) é importante porque fornece informação precisa sobre a qualidade da água. Em 6 das publicações (11%) os autores utilizaram um método que combina monitorização de dados e modelação. Em outras 6 publicações (11%) aplicou-se apenas um modelo para estimar a qualidade da água. A modelação pode ser um recurso útil quando o orçamento é limitado pois alguns modelos são de uso gratuito e facilmente acessíveis via internet. Verificou-se que vários dos modelos utilizados são originários dos EUA, tendo por isso, objetivos e características adaptadas à realidade desse país. Este aspecto realça a necessidade de prudência na utilização desses modelos noutros países, sendo crucial uma discussão crítica dos resultados fornecidos pelos mesmos. 5 das publicações (9%) analisadas recorrem a uma metodologia que combina a monitorização, a análise estatística e a modelação. Com efeito, quando existe uma grande matriz de dados, os investigadores necessitam de uma forma eficiente de interpretação da informação, algo que é possível recorrendo à estatística. Em 3 das publicações (5%) é utilizada uma metodologia que combina a monitorização, a análise estatística e a modelação. Todos estes métodos são válidos para a avaliação da qualidade da água, embora requerendo diferentes recursos materiais e humanos para a sua implementação.

Verificou-se que a avaliação da qualidade da água por vezes também é feita utilizando outro tipo de amostragem, além da água e que estas técnicas permitem angariar informação útil para a compreensão das condições na massa de água. Estas quatro outras técnicas de monitorização incluem a amostragem do ar; a recolha de sedimentos, de fitoplâncton e de tecidos de animais aquáticos.

Antes de se analisar a qualidade da água um rio, lago ou albufeira, é importante considerar as condições ambientais na bacia hidrográfica. Deve ter-se em consideração as condições gerais climáticas, geográficas e de uso do solo da área em estudo.

É importante caracterizar a precipitação anual (dados de precipitação podem ser obtidos de postos udométricos da bacia hidrográfica ou adjacentes a esta), a temperatura média anual (valor que pode ser recolhido nos registos dum instituto meteorológico), quais os diferentes padrões na estação seca e na estação pluviosa, a duração da monção em cada região, etc. Por exemplo, durante a época das chuvas, a descarga de poluentes é influenciada principalmente pelo escoamento superficial. Na fase inicial da chuvada, o pico da concentração de poluentes surge antes do pico do caudal correspondente a essa chuvada. Este aspeto evidencia a necessidade de caracterizar e gerir a descarga inicial quando se pretende controlar poluentes de origem difusa.

É ainda necessário compreender as condições geográficas particulares da zona em estudo. Por exemplo, para se avaliar o efeito das atividades humanas deve-se identificar a existência de complexos industriais, núcleos habitacionais e de exploração mineira. Entretanto, é importante detetar a presença de fontes de poluição difusa. Por exemplo, as parcelas de cultivo de arroz construídos em zonas baixas representam um risco para o ambiente durante a época das chuvas uma vez que esses talhões, quando inundados, transbordam directamente para as massas de água adjacentes. Por outro lado, os fatores naturais que controlam a qualidade da água, como a natureza dos afloramentos rochosos expostos à interação com a água, também condicionam a composição química da água.

Apesar do progresso considerável no desenvolvimento e aplicação de regulamentação para controlar a poluição de origem pontual e difusa, o estado de poluição em rios, lagos e albufeiras de países asiáticos não tem melhorado. Isto traduz o ritmo lento de investimento em novas infra-estruturas para controlo da poluição e a crescente pressão demográfica.

As leis e regulamentos relativos à água e o envolvimento da população na sua aplicação podem ter um papel relevante e construtivo na proteção do meio ambiente. Num futuro próximo, para proteger os recursos hídricos asiáticos de maior degradação, será extremamente necessária uma ação rápida no controlo das diversas origens de poluentes duma dada região. É essencial fomentar medidas de recuperação ambiental bem como o tratamento de efluentes industriais e de águas residuais domésticas. É também importante evitar a entrada direta de escorrências agrícolas ou de lixiviados de explorações mineiras. Por último, é igualmente necessária uma regulamentação ambiental mais rigorosa destinada a garantir a qualidade da água, apoiando as estratégias de proteção e gestão ambiental.

Teria sido possível extrair mais informações através da análise da amostra de 57 artigos utilizada. Por exemplo, teria sido interessante comparar o nível de concentrações de determinados poluentes nos diferentes países Asiáticos. No entanto, o limite de 3 meses para a duração do estudo impediu a execução deste tipo de análise. Apesar disso, os objectivos foram atingidos, tendo-se conseguido um enquadramento dos problemas de qualidade da água mais frequentes em países asiáticos, bem como conhecer as metodologias mais utilizadas para a avaliação dessa mesma qualidade.

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Al	Aluminium
AS	Anionic surfactants
As	Arsenic
BOD_5	5-day biochemical oxygen demand
BPA	Bisphenol A
CA	Cluster analysis
Ca	Calcium
$COD/COD_{Cr}/ COD_{Mn}$	Chemical Oxygen Demand/COD based on Cr/COD based on Mn
Cd	Cadmium
Cl^-	Chloride
CN	Cyanide
CNP	Chlornitrofen
Cr	Chromium
Cr^{6+}	Hexavalent chromium
Cu	Copper
DA	Discriminant analysis
DDT	Dichlorodiphenyltrichloroethane
DEHP	Di-ethyl(hexyl)phthalate
DL-PCBs	Dioxin-like polychlorinated biphenyls
DO	Dissolved oxygen
DOP	Di-n-octyl phthalate
EA	Econometric analysis
EC	Electrical conductivity
ECM	Export coefficient model
EcoHAT	Ecohydrological Assessment Tool
E. coli	Escherichia coliforms
EPA	Environmental Protection Agency
EU	European Union
F/ F^-	Fluoride
FA	Factor analysis
FCA	Fuzzy comprehensive assessment
F. coli	Fecal coliforms
Fe	Iron
HCB	Hexachlorobenzene
I_{geo}	Geoaccumulation index
K	Potassium
MD	Monitoring data
MDLs	Multidimensional Dynamic List Scheduling
Mg	Magnesium
MLR-APCS	Multivariate linear regression of absolute principal component scores
Mn	Manganese

MONERIS	Modeling Nutrient Emissions in River Systems
MPN	Most Probable Number
N	Nitrogen
Na	Sodium
NDMA	N-nitrosodimethylamine
NH_3-N/ NH_4^+ -N	Ammonia nitrogen
NO_2-N	Nitrite nitrogen
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_3^- -N	Nitrate nitrogen
NPS	Non-point source
NP	Nonylphenol
Ni	Nickel
OCPs	Organochlorine pesticides
orgN	Organical nitrogen
P	Phosphorus
PAEs	Phthalate esters
PAHs	Polycyclic aromatic hydrocarbons
PBDEs	Polybrominated diphenyl ethers
Pb	Lead
PCA	Principal Component analysis
PCBS	Polychlorinated biphenyls
PCDDs	Polychlorinated dibenzo-p-dioxins
PCD/Fs	Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans
PCDFs	Polychlorinated dibenzofurans
PCP	Pentachlorophenol
PFA	Principal Factor analysis
PFOA	Perfluorooctanoic acid
PFCs	Perfluorinated compounds
POPs	Persistent organic pollutants
QWASI	Quantitative water–air–sediment interaction
S	Sulfur
SO_4^{2-}	Sulfate
SPM	Suspended Particulate Matter
Sr	Strontium
SS	Suspended Solids
SWAT	Soil and Water Assessment Tool
PET	Polyethylene terephthalate
TCd	Total cadmium
TDS	Total dissolved solids
TEQ	Toxicity Equivalency Quantity
TGR	Three Gorges Reservoir
THg	Total mercury
TKN	Total Kjeldahl nitrogen

TN	Total nitrogen
TP	Total phosphorus
TPb	Total lead
TS	Total solids
TSS	Total suspended solids
T–CN^-	Total cyanide
V-ArOH	Volatile phenol
VOCs	Volatile organic compounds
VP	Volatile phenolic
WHO	World Health Organization
WQ	Water Quality
WWTP	Wastewater Treatment Plant
Zn	Zinc
Σ_{15}OCPs	Sum of 15 organochlorine pesticides concentration
ng/L	Nanograms per litre
µg/L	Micrograms per litre

1. Introduction

1.1 The importance of water resources

Water is one of the most important parts of the ecological environment, and is an indispensable substance to life and productive activities of human. The availability and quality of water always have played an important part in determining not only where people can live, but also their quality of life. Besides, all plants and animals must have water to survive. If there was no water there would be no life on earth. We may summarize the importance of water in three main points:

1) Regulating climate. Water is the major component of atmosphere, though the atmosphere contains only a millionth of the world’s water, the interaction of circulation of atmosphere and water is determined by the Earth's water cycle movement. The water in the atmosphere plays an important role in the global energy balance; the dynamic process of water circulation can impact on energy transfer in different areas.

2) Water is the essential matter to all living things. Life can live without food for longer than they can without water. A person's or an animal’s survival and good health depends on drinking water - it is necessary for the digestion and absorption of food; helps maintain proper muscle tone; supplies oxygen and nutrients to the cells; rids the body of wastes. In each region, water is a key factor in determining vegetation. It can also determine the type of animal community. Historically, humans have settled near sources of water, either river or lake or the sea or the ocean - it is a vital resource necessary for survival, contributing to human health, irrigation, and transportation.

3) Fresh water is also used in urbanized areas and industrial processes. It is estimated that 69% of worldwide water use is for irrigation, with 15-35% of irrigation withdrawals being unsustainable. It takes around 2,000 - 3,000 liters of water to produce enough food to satisfy one person's daily dietary need [1]. Most items we use every day require water in their manufacturing. For example, it takes 560 liters of water to produce a Sunday newspaper, 269 liters to make a kilogram of steel, and 1,329 liters to produce a kilogram of aluminum. It requires almost 3,028,000 liters of water a year to provide one person with food. Water is used not only to grow food, but to process food as well. It takes 560 liters of water to make a loaf of bread and 2,397 liters to make a kilogram of ground beef [2]. Large amounts of water are needed to produce energy and significant energy is used to treat and transport water to consumers. Figure 1 demonstrates this interdependency. It is estimated that 22% of worldwide water is used in industry [4]. Major industrial users include hydroelectric dams, thermoelectric power plants, which use water for cooling, ore and oil refineries, which use water in chemical processes, and manufacturing plants, which use water as a solvent. It is estimated that 8% of worldwide water use is for household purposes [4]. These include drinking water, bathing, cooking, sanitation, and gardening. Recreational water use is usually a very small but growing percentage of total water use. Recreational water use is mostly tied to reservoirs. Fresh water is used in settlements to meet domestic demands (Figure 2) and also in municipal waste water systems, industrial waste water treatment plants in agriculture, and for the dissolution and removal of dirt and waste [5]. Water is used for irrigation in

agriculture; the water consumption in each hectare of different crops is as follows: wheat is 23~34 tons, cotton is 22~27 tons, beets is 31~40 tons; also on the food processing industry, 1 kilogram of meat consumes water 31.5 tons; on the industry, a ton of paper consumes water 31.5 tons, while a ton of synthetic rubber consumes water 27500 tons [6].

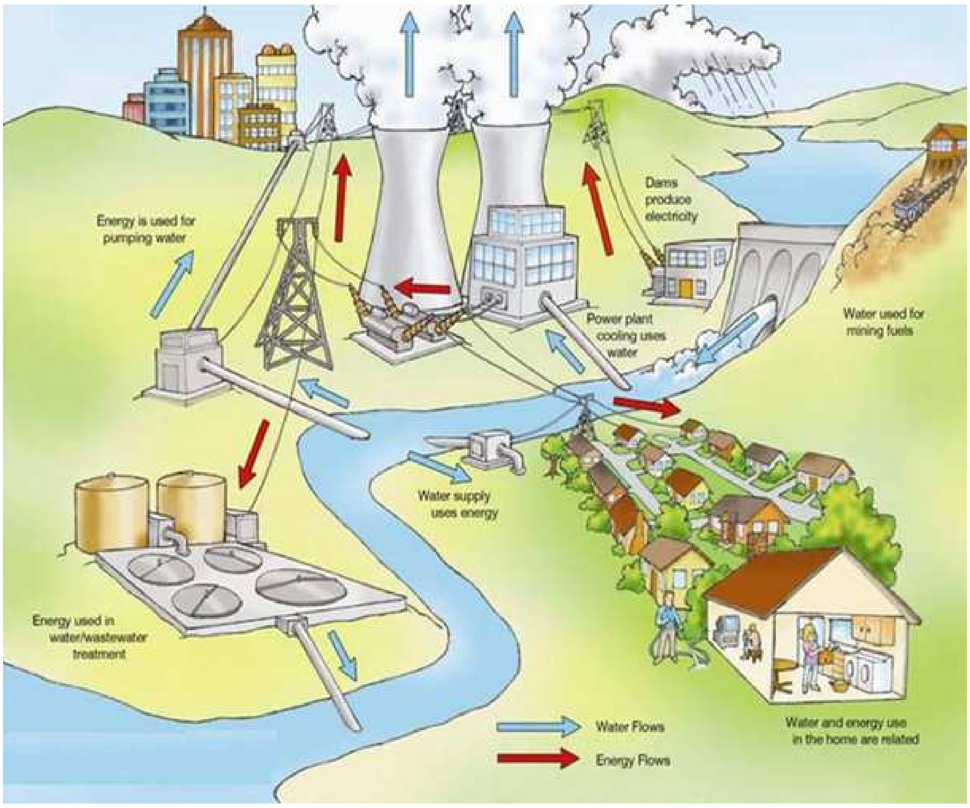

Figure 1: Energy-Water Relationship [3]

1.2 Water resources quantity and quality

The total volume of water on Earth is estimated at 1338×10^6 km^3. About 70% of the Earth's surface is covered by oceans. The salt water in the seas and oceans represents 97% of the total water on Earth, the remaining 3% being freshwater (Figure 3). Freshwater is distributed in different components: permanent snow cover and glaciers, rivers, lakes and groundwater. It can be seen that the greatest part of total freshwater is trapped in polar glaciers and ice sheets, and therefore it is not directly accessible for use. Only 0.3% of the freshwater on Earth is surface water, in the form of lakes (87%) and rivers (2%) [5].

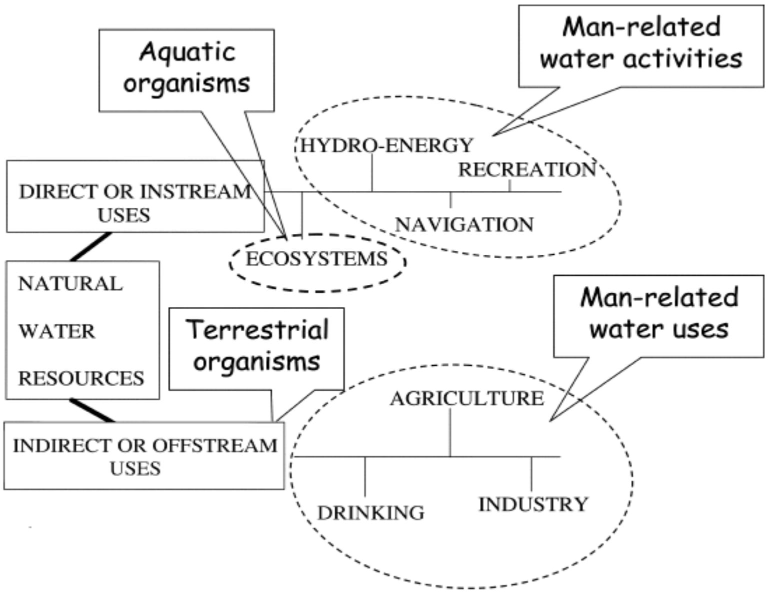

Figure 2: Direct and indirect uses of water resources by man and ecosystems [5]

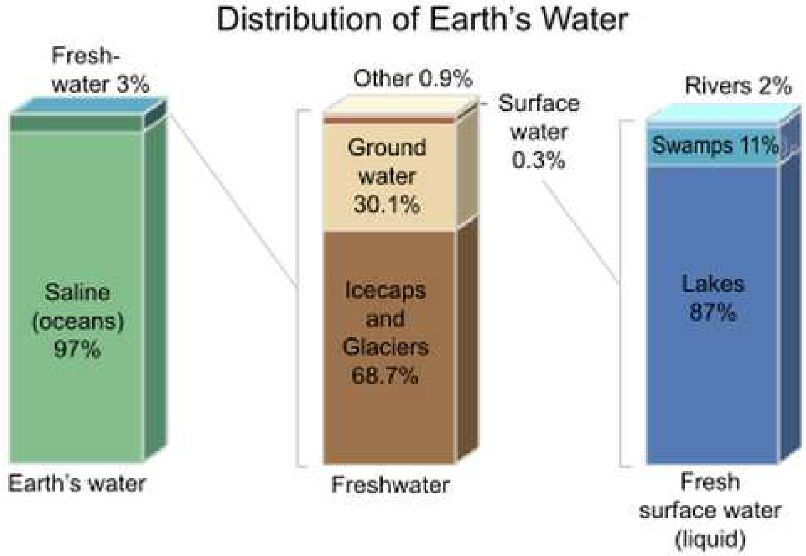

Figure 3: A graphical distribution of the location of water on Earth [7]

Water quality standards were developed by man to help to protect and maintain the water quality necessary to meet designated or assigned uses, such as swimming, recreation, public water supply, and aquatic life. Water bodies may be assigned to specific tiers depending on the level of protection necessary to maintain high quality and existing uses. The higher the tier, the more stringent the requirements are for protection. For example, in China, surface water bodies such as rivers, lakes and reservoirs are divided into five classes according to the utilization purposes and protection objectives [8]:

a) Class I is mainly applicable to the water at the national nature reserves.
b) Class II is mainly applicable to first class of protected areas for centralized sources of drinking water, the protected areas for rare fishes, and spawning fields of fishes and shrimps.
c) Class III is mainly applicable to second class of protected areas for centralized sources of drinking water, protected areas for common fishes and swimming areas.
d) Class IV is mainly applicable to the water areas for industrial use and entertainment but not bathing or swimming.
e) Class V is mainly applicable to the water bodies for agricultural use and city landscape.

Water quality may be considered as a set of biological, chemical, and physical characteristics of water in combination with intended uses and also to be compared to standards. Water pollution is the contamination of natural water bodies by chemical, physical, radioactive or pathogenic microbial matter [9]. It is well known that natural aquatic systems have a capacity to receive a certain quantity of pollutants discharged into them, but when the pollutants discharged exceed their capacity of self-purification, the water body will be damaged. Today, approximately 90% of the sewage and 70% of the industrial wastes are produced and discharged untreated into watercourses in developing countries. An estimated 1,000 Indian children die of diarrheal sickness every day. In China, nearly 500 million people lack access to safe drinking water [5]. In addition to the acute problems of water pollution in developing countries, developed countries continue to struggle with pollution problems as well，although in different scenarios. According to a recent study by the European water industry, pesticide contamination is most acute in lowland river areas, particularly in Belgium, France, the Netherlands and the UK [10]. In the United States, 45% of assessed stream miles, 47% of assessed lake acres, and 32% of assessed bays and estuarine square miles were classified as polluted in recent years [11]. As can be seen from Table 1, different types and origins of pollution can influence a water body to varying degrees.

Table 1: Overview of organic and non-organic pollutants typically found in freshwater systems [12]

Pollution type	Main sources	Adverse effects
Organic Matter, food waster, Carbon-based substances.	Industrial wastewater and domestic sewage.	Decomposition leads to oxygen depletion, stressing, or suffocating aquatic life.
Toxic Organic Compounds and Micro-Organic Pollutants, PCBs, pesticides, pharmaceuticals, solvents.	Industrial, motor vehicles, agriculture, gardeners, municipal waste.	Changes in oxygen levels and decomposition rate of organic matter in water, and in biodiversity.
Heavy metals, cadmium, lead, zinc, copper.	Industries and mining sites.	Persist in sediments and wetlands. They poison fish and sink into sediments.
Pathogens and Microbes, cryptosporidium, salmonella, shigella.	Domestic sewage, livestock.	Spread of infectious diseases and parasites.
Nutrients, nitrogen and phosphorus.	Run-off from agriculture lands and urban areas, industrial discharge.	Over-stimulates growth of algae, which, when they decompose, use oxygen in water, stressing or suffocating aquatic life.

The origin of water contaminants can be classified into two groups: those from natural sources, such as the soil by geological dissolution or rainfall erosion, etc., and anthropogenic sources, such as fertilizers, industrial and domestic wastewater [13]. The quality and quantity of the water can be affected by discharge from point sources and also by extensive drainage from agriculture areas and waste lands in basin, hence, water pollutant sources can also be divided into two categories: Point source pollution and Non-point source (NPS) pollution.

Point source pollutants enter the water from a specific point through a sewer pipe, a ditch, or a culvert. Common point sources of pollution are discharges from factories and municipal sewage treatment plants [2]. Specifically, urban storm water runs off buildings, manufacturing and industrial sites, streets, and parking areas into storm sewers, where it flows untreated into water ways. It carries with it oil, grease, trash, salts, heavy metals, and other pollutants. This pollution is relatively easy to collect and treat, but needs investment in building proper infrastructures and in human resources. Point source pollution abatement is essentially an end-of-pipe control.

NPS pollution occurs when potentially polluting substances leach into surface waters and groundwater as a result of rainfall, soil infiltration and surface runoff. The source of this pollution, usually due to a recent or past activity on land, is based on a widespread input in water resources of contaminants of many types. It actually comes from a variety of sources, such as farm fields, animal feedlots or pastures, residential developments, roadsides, and urban parking lots. Sediment, plant nutrients, toxic materials, and animal wastes are the major types of diffuse pollutants [14]. Typical examples of diffuse pollution include the use of fertilizer in agriculture and forestry, pesticides from a wide range of land uses, contaminants from roads and paved areas, and atmospheric deposition of contaminants arising from industry. Construction site runoff carries soil and debris into streams and lakes. Agricultural runoff carrying barnyard effluent, fertilizers, pesticides, and topsoil can pollute surface waters [15, 16].

NPS and point source pollution always co-exist in the environment [14]. The differentiation between point and nonpoint sources of contamination sometimes may depend on the scale at which the problem is considered.

For example, the houses in suburbs that do not have a combined sewer system, but individual septic tanks:
i) At the local scale (implies distances from a few meters to a few hundred meters and areas as large as a few square kilometers), each septic tank maybe considered as a point source;
ii) At the regional scale (range from tens to thousands of square kilometers), however, the combined contamination from all the septic tanks in a suburban area may be considered a nonpoint source of contamination to a surface water body [17].

In general, according to [18], pollution management can be divided into four categories:

a) Source control measures;
b) Hydrologic modification of water resource;
c) Reduction of delivery of pollution from the source area to receiving water body;
d) End-of -pipe removal of pollutants.

1.3 Variables that affect the condition of water resources

In this master thesis, the focus is placed on two types of surface water resources: rivers and confined water bodies (lakes and reservoirs). The major problem of confined water bodies is usually the pollution from agriculture, industrial sewage and domestic wastewater [19]. Confined water bodies may be regarded as an almost static system. On the contrary, in rivers, the situation of pollution must be seen as a dynamic process. The water quality of freshwater at any point on the catchment basin changes in different periods of the year and has also spatial variations [20]. It reflects the combined effects of local, regional, global differences in climate, water flow and human activities [21]. Three main influencing factors are described separately in the following sections, although they are also interconnected.

1.3.1 Influence of climate on the condition of water resources

Climate and climate change affect the hydrological cycle and the atmospheric water vapor content, thereby changing patterns, intensity of precipitation, thus changing the runoff over watersheds and the stream flow in rivers [22]. To a certain degree, the water quality of rivers, lakes and reservoirs can be directly affected by changes in the amount of precipitation runoff. According to the climate the whole year may have different seasons. Typically, there is a dry season which is a period of low or no rainfall; and a rainy season which is the time of the year when most of a region's average annual rainfall occurs.

In the dry season, due to the low or no rainfall, even without the presence of non-point sources of pollution, the quality of lakes and reservoirs can be critical. Confined types of fresh water systems may allow high dilution of pollutants decreasing their possible impacts; even so the volume shortage in the dry season may cause a decrease of the water quality [19]. If there are many point sources, such as wastewater from paper mill or other kind of factories, the confined water bodies may get polluted. All these processes are very much dependent on the specific characteristics of the water mass, the presence of pollutant sources at the catchment and the regional climate pattern. Unlike lakes or reservoirs, rivers can wash away some contaminants by keep running through the whole area and moving into another river or the ocean. In spite of that, pollutants attached to particles, may settle and accumulate at the river bed.

In rainy seasons, heavy rainfall and floods cause erosion and transport of materials into water bodies. For a given watershed with certain pollution sources, different combinations of pollutants discharges may cause different impacts in the water quality [19]. If there is just small-scale runoff pollution to a given confined water body, the water quality may even improve during the rainy season because the water level rises and dilutes the concentration of contaminants. On the contrary, if runoff pollution is a serious issue, the water quality starts to deteriorate. Meanwhile the structure and the function of plankton population may be affected. It is common that the average concentrations (biochemical oxygen demand loadings, ions and trace metals) of pollutants in the inflow water are highest than at confined water bodies [19, 23]. Similarly, the rainstorm will cause river levels to rise sharply and wash out the substances which remained on road or farmlands, and then may cause the deterioration of water quality, particularly the increase in turbidity. Other things being equal, the effects of organic and microbiological pollution should be worse in hot than in cold countries. Offensive smells, arisen chiefly when the rate of biological oxidation is greater than the rate of oxygen supply, which occurs with high temperatures.

1.3.2 *Influence of human activity on the condition of water resources*

A major hazard to the water bodies is the wastewater discharged from factories and business establishments, if sewage or partly treated sewage is directly discharged into surface water such as rivers, the water will get contaminated [23, 24]. It can be seen from Figure 4 that the continuing increment in global population is increasing the demand on freshwater supply, decreasing the quality of water and increasing flood problems.

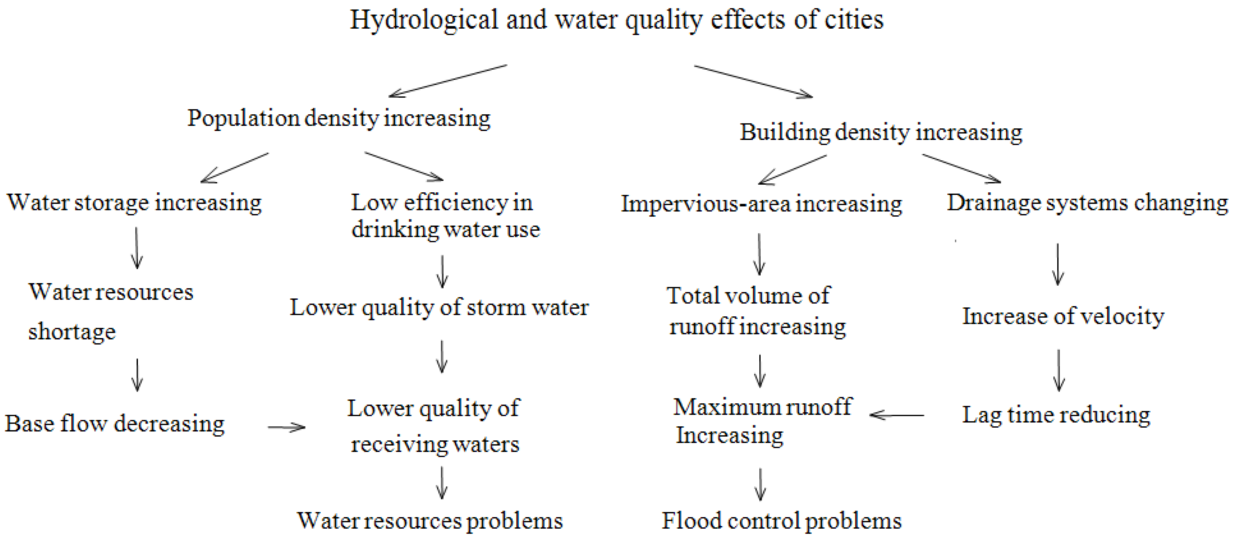

Figure 4: Influence of human activity on the condition of water resources. Adapted from [25]

In general, according to [23], the effects of the human activity on water resources can be divided into four factors:

1) Agricultural development;
2) Application of agricultural chemicals (nitrogen and pesticide);
3) Urban and industrial development;
4) Irrigation and drainage systems of the land surface development.

1.3.3 *Influence of the land use of the catchment on water resources*

Major known sources of water pollution are municipal, industrial and agricultural wastewater runoff. The most polluting of them are sewage and industrial waste discharges. Industrial effluents may contain heavy metals, acids and hydrocarbons. Agricultural run-off contains nitrogen compounds and phosphorus from fertilizers, pesticides, salts, poultry wastes and washes down [23]. As a result, if the rivers, lakes or reservoirs are located near industrial parks or farmlands, the quality of water can be badly affected. According to the source and nature of pollutants, they can migrate with the water flow, therefore the water quality downstream would be inferior compared to the upstream, and the pollution in small tributaries should be more serious than that in the main channel [20]. For example if one takes China as a whole, the water quality in Southern rivers is superior to Northern rivers; and rivers in the Central and Western regions compared to Eastern developed regions have a better water quality [26].

1.4 The role of legislation in the water quality of rivers, lakes and reservoirs

Water quality issues have arisen as a result of the rapid growth of population, increased urbanization, expansion of industrial activities, and disposal of domestic and raw sewage into nearby water courses, increase use of fertilizer and agrochemicals as well as lack of environmental regulations [23]. For effective management of wastewater, there should be appropriate laws and affordable techniques for wastewater treatment and control [27].

Water laws and public involvement in enforcement have played a constructive and indispensable role in environmental protection. In the case of China, since the early 1980s, modernization efforts have drawn attention to many previously neglected problems like non-point source pollution, environmental health and safety [28].

The roots of legislation are based on prevention, polluter-pays principle and principle of cooperation [29]. An example of a particularly successful bilateral agreement utilizing the pollution prevention and abatement principle can be found in the 1978 Agreement between Canada and the United States on Great Lakes Water Quality. The Agreement provides a very intensive and detailed series of provisions on the prevention of pollution of the Great Lakes, which lie on the border between the two nations. Article II articulates that the purpose of the Agreement is “to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem.” The treaty further defines general and specific objectives related to the protection of Great Lakes waters and defines water quality standards and programs and measures that should be implemented in furtherance of the objectives [11].

In Europe, the EU Water Framework Directive 2000/60/EC establishes the importance of preserving water quality through policies applied at the watershed level, given the strong links existing among ecological, hydrological, and hydro geological systems. For surface waters, the environmental objectives of the Directive concern their protection, improvement and restoration by applying specifically devoted monitoring campaigns and also performing management practices planned at the river basin scale [30]. The countries from the European Union should obey this law to the letter and amend their laws based on circumstances within each country.

The enforcement of applicable laws will improve the condition of water resources, but only a combination of education, scientific knowledge and planning can provide mechanisms for slowing the rate of degradation and provide human and environmental protection [21]. Each individual can play an important role by practicing conservation and by changing certain everyday habits.

2. Objectives and Methods

This work has the objective of identifying the most common water quality problems in Asian countries and to enumerate and analyze the methodologies used for assessment of water quality conditions of both rivers and confined water bodies (lakes and reservoirs). Due to the agriculture activities, lack of technological treatment and rapid development of urbanization and industrialization, most developing Asian countries have been confronted with a serious crisis in water resources, and pollution is also increasing.

Since this Master Thesis has the time duration of three months, time is a constraint in this work and this is the reason why the objective is to gather an “approach to the issue”.

This research, which is just an “approach to the issue” due to time constraints, was carried out by using the last 15 years related international scientific literature, searched on international journals database. The sample gathered was analyzed taking into consideration the geographical location; the pollutant sources, the water resource and its quality.

The tasks performed may be summarized in the following 6 steps:

1) Literature revision focused on publications from the last 15 years.
2) Brief characterization of water resources in Asian countries based on the literature sample obtained in step 1).
3) Identification of the most relevant Asian water quality problems in rivers, lakes and reservoirs.
4) Evaluation of the most relevant point and diffuse pollution sources/ pollutants.
5) Identification of the methodologies used for evaluation of water quality in rivers, lakes and reservoirs.
6) Analysis of the methodologies used and their suitability to tackle the existing problems.

3. Results of literature research

3.1 Overview of study sample

In order to have a representative and comprehensive sample of studies published in scientific journals, the adopted procedure was: i) to search in scientific data bases using relevant key words; ii) to consider recent studies, published from 2000 up to 2013, and iii) to the best of the author's ability ensure that the obtained sample of studies concern both rivers, lakes and reservoirs from all over the Asian continent.

At the end of the search, 57 published papers were selected; 35 of them dated from 2008 to 2013, meaning that most of the papers (61%) are quite recent. It was decided that the sample of paper was sufficient for the accomplishment of the study objectives.

Figure 5 shows the location, quantity and date of the literature sample. It shows clearly that many different climatic Asian regions and research backgrounds were covered. Table 2 presents a summary of the 57 studies that will be analyzed in this report.

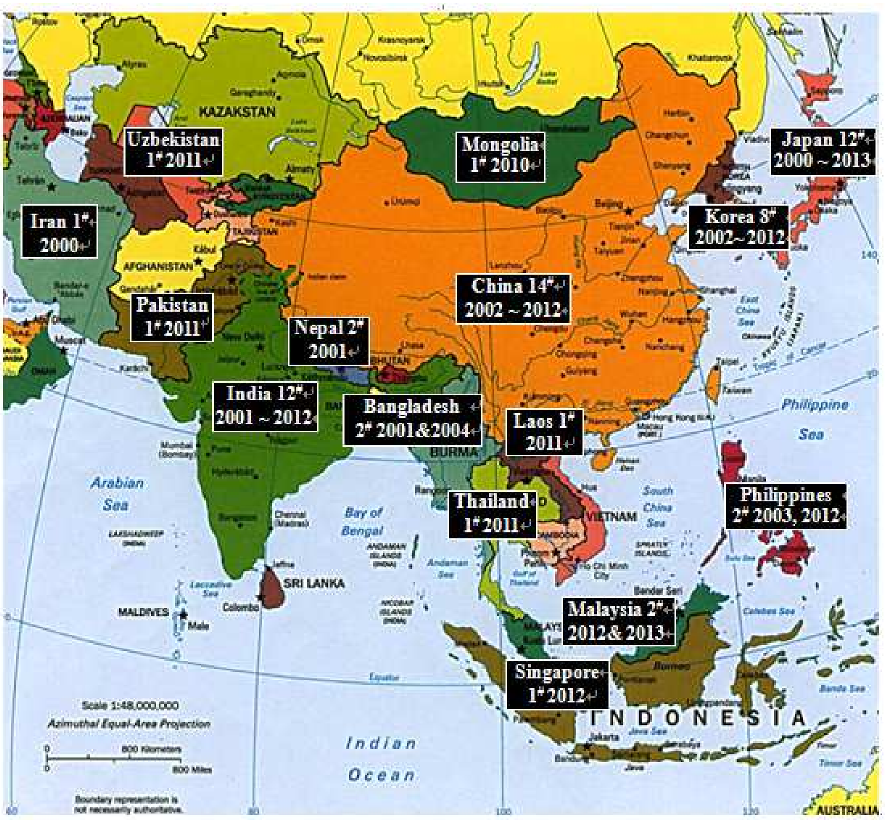

Figure 5: Location, number and date of the literature references selected for the analysis

Table 2: Summary of the 57 studies used for analyzing the water quality issues in rivers, lakes and reservoirs of Asian countries

Reference & Date		Water Type	Target pollutants	Pollution sources	Methodologies used
China	[31] 2011	River	DO, EC, TSS, TS, Zn, BOD_5, COD, turbidity, E.coli, F.coli, NH_4^+-N, As, F, NO_3-N, TKN, TP, Cr, Pb, Ni, Mn.	Organic pollution, non-point pollution, industrial pollution.	MD & CA, DA, PCA
	[32] 2011	River	TN, TP.	Non-point sources: rural domestic wastes, distributed livestock farms, fertilizers and pesticides.	MD & ECM
	[33] 2004	River	PAHs.	Leakage of crude oil and the refined products from urban vehicle traffic.	MD & PCA
	[34] 2002	Reservoir	TP, TN, COD.	Loss of nutrient from chemical fertilizer and pollutants of animal waste.	MD
	[35] 2012	River Lake and Reservoir	POPs including: OCPs, PCBs, PBDEs, PCDD/Fs.	OCPs: dicofol; PCBs: capacitors and power transformers and paint additives; PBDEs: plastics, textiles, and imported e-waste; PCDD/Fs: municipal solid waste incineration.	MD
	[36] 2009	Reservoir	NO_3-N, NH^{4+}-N, and P.	Agriculture pollution.	EcoHAT
	[14] 2010	River Lake & Reservoir	TN, TP, COD, BOD.	NPS: agriculture pollution, street runoff, deposition of atmospheric pollutants, mine sites.	SWAT Model
	[37] 2011	Reservoir	PCDD/Fs.	Atmospheric transport and deposition.	MD
	[38] 2010	River	Antibiotics.	Hospitals, nursery, slaughter house and wastewater treatment plant.	MD
	[39] 2009	Lake	PAH.	Vicinity of urban and industrial areas.	MD
	[22] 2012	Reservoir	Annual NH_4^+-N and TP.	Municipal, industrial, and agricultural sources.	MD & SWAT model
	[40] 2009	River	DO, TDS Cl^-, $SO4^{2-}$, COD, BOD, NH_4^+-N, TP.	Industrial, agriculture and domestic pollution.	MD
	[20] 2010	River	Cr^{6+}, V-ArOH, THg, NH_3-N, F^-, TCd, CODMn, DO, BOD_5, TP, TPb, petroleum.	Industrial wastewater, agricultural activities and urban runoff.	MD & FCA & FA & UNMIX model
	[41] 2011	River	COD_{Mn}, COD_{Cr}, DO, PO, BOD_5, TP, TN, NH_4, Cu, Zn, Pb, Cd, As, Cr, CN, VP.	Discharge of industrial and domestic wastewaters.	MD & PCA & MLR-APCS model

Japan	[42] 2002	Lake	TN,TP.	Rice paddy fields.	MD & Mass balance model
	[43] 2008	Lake	S and Sr isotopes.	Agricultural activity.	MD
	[44] 2002	River	Heavy metals.	Geological factors.	MD
	[45] 2012	River	TN,TP, SS.	Sewage, plant effluent and agricultural activity.	MD & SWAT model
	[46] 2012	River	Paddy herbicides and their transformation products.	Used for rice crop protection in paddy fields.	MD
	[47] 2000	River	As, Cu and Zn.	Mine drainage.	MD
	[48] 2011	River	NDMA.	Formed from precursors such as natural organic matter by chloramination or chlorination in the presence of high concentrations of NH3.	MD
	[49] 2010	River	PFCs: PFOS, PFHxA, PFOA, and PFNA.	Different point and non-point sources: surfaces factories.	MD
	[50] 2013	Lake	TP, TN, COD.	From surrounding watersheds.	MD
	[51] 2010	Reservoir	Pesticide.	Rice paddy effluents.	MD
	[52] 2011	River	PCDDs, PCDFs, DL-PCBs.	From a large area of paddy fields.	MD & PCA
	[53] 2002	River	TN, TP, SS.	Chemical fertilizer from the agricultural land and livestock wastes.	MD
India	[54] 2006	River	DO, BOD, TSS, NO_2–N, Mg, K, NO_3–N, NH_4–N, TN, Ca, Na, PO_4–P, TP, SiO_4–Si, TDS, Cl^-.	Municipal and industrial wastewater discharge.	MD & FA & CA
	[55] 2009	River	Heavy metals: Cd, Cr, Cu, Fe, Mn, Zn and Pb.	Industrial and urban discharges.	MD
	[56] 2002	Reservoir	Organic contaminants.	Industrial townships and coal mine.	A suit of QWASI models
	[57] 2002	River	Nitrogen and its compounds.	Agricultural runoff.	MD& Mass balance model
	[58] 2011	River	Heavy metals: Cr, Cu, Fe, Mn, Ni, Pb, Zn.	Industrial effluents, agricultural flows and domestic sewage.	MD & CA
	[59] 2004	River	Organic pollutants, chemicals and heavy metals.	Discharge of domestic sewage, industrial effluents and run-off from land-based activities such as agriculture.	MD & Econometric analysis; Ordered Probit model

	[60] 2002	Lake	Pesticides.	Fish farms.	MD
	[61] 2006	Lake	Toxic heavy metals: Ca, Mg, Fe, Al, Mn, Ba, Zn, Ti, Cu, Cr, Co, Ni, Pb, Cd.	Industry, municipal wastewater, atmospheric pollution, urban runoff, river dumping and shore erosion.	MD
	[62] 2012	River	EC, DO, TDS, Ca, Mg, Na, K, Fe, HCO_3, NO_2 -N, NO_3-N, P-inorg, P-tot, chloride, SiO_2.	Various kinds of anthropogenic activities: urbanization, rise in tourism, industrialization, fertilizer intensive agricultural activities.	MD
	[63] 2005	River	BOD, Cl, F, PO4, NH_4–N, NO3–N, TKN and Zn.	Municipal and industrial wastewater discharge.	Multivariate statistical techniques
Korea	[64] 2002	River	DO, BOD, N and P.	Domestic sewage, industrial wastewater, livestock discharge, and urban and agricultural runoff.	QUAL2E
	[65] 2002	River	BOD, SS, TN, TP.	Nonpoint source pollution.	NPS runoff quality simulation model
	[66] 2012	Lake	PBDEs.	Large industrial complexes.	MD
	[67] 2011	Lake	NPs, COP and cholestanol.	Coastal industrialized region.	MD
	[68] 2002	River	N and P.	Point and NPS pollution.	QUAL2E model
	[69] 2009	Reservoir	DO, BOD, COD, SS, TC, TN, TP, SD, EC, NO_3-N, NH_4-N, and PO_4-P.	Non-point and point source inputs: agricultural activities and urban/industrial wastewater.	MD & PCA
	[70] 2004	Lake	NP.	Industrial complexes.	MD
	[71] 2002	River	DO, SS, BOD, TOC, COD_{Cr}.	NPS pollution.	MD
Malaysia	[72] 2013	5 River	Plasticiser.	Malaysia has undergone extensive land conversion from agricultural use to urban–industrial–commercial use.	MD
	[73] 2012	River	Solid, organic matters, nutrient, heavy metals.	Mining and urban development.	MD& PFA &Artificial neural network model
	[74] 2003	River	BOD,DO, COD, org N.	Domestic wastewater.	MD

[75] 2012	Lake	Pesticides.	Agricultural activities.	MD
Pakistan [76] 2011	Lake	TDS, turbidity, cond, Mg, Cl, DO, total coliform, facel coliform, BOD.	Agricultural, and poultry sectors.	MD
Thailand [77] 2011	River	PFCs.	Industrial and domestic activities.	MD
Laos [78] 2011	River	Bacteriological contamination.	Urban household wastewater.	MD
Israel [79] 2000	Lake	SPM.	SPM in lakes can emanate from various primary and secondary sources.	A dynamic mathematical model
Singapore [80] 2012	Reservoir	PFCs.	Point sources: leaking sewer lines, chemical spills; NPS: painted buildings, road surfaces.	MD
Mongolia [81] 2012	River	N and heavy metal.	Agroindustrial farming complex and activities of gold mining industry.	MONERIS model
Uzbekistan [82] 2011	Reservoir River	Cu, Pb, Ni, As, Cr and DDT.	Agricultural and industrial pollutants.	MD
South Asia [83] 2004	River	POPs, heavy metals.	Direct or un-regulated discharges in populated regions; fertilizers run-off from agricultural field; mining activities.	MD
South Asia [84] 2001	River	BOD, DO.	Urban activities.	MD

3.2 Discussion of the literature sample

Concerning the countries, from the 57 published papers, as Figure 6 illustrates, 14 of them are about China; 12 about Japan; 11 about India; 8 about Korea; 2 of them concern Malaysia and Philippines. Finally, several countries are represented with 1 reference: Pakistan, Thailand, Laos, Israel, Singapore, Mongolia, Nepal, Bangladesh, Uzbekistan, respectively. As a result, it is observed that China and India have the most representative sample, from all the developing countries in Asia. On the other hand, Japan with 12 studies is the only developed country in Asia; therefore it is an interesting case to be studied.

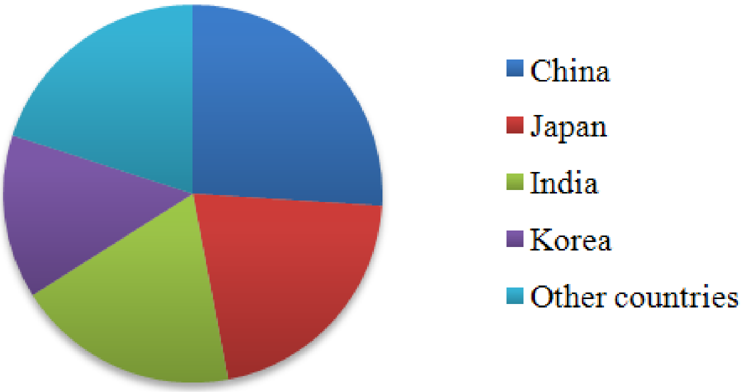

Figure 6: Different countries distribution in the literature sample

In terms of water body type from the 57 analyzed papers, as Figure 7 demonstrates, 39 references concern rivers, 14 references concern lakes, and 10 references are about reservoirs. Among them, 2 papers discussed simultaneously river, lake and reservoir; and 1 paper analyzed both a river and a reservoir.

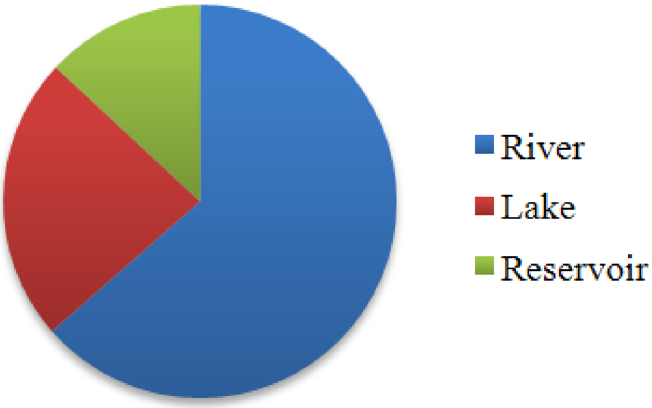

Figure 7: Different water body types of the literature sample

Concerning the pollutant source types, like Figure 8 demonstrates, 36 references are about point pollutant sources, and 45 references studied NPS pollutant. Among them, 24 references include both the point and NPS pollutants. More specifically, 31 references mentioned industry wastewater, 30 mentioned agriculture wastewater, 24 references concerned domestic wastewater, and 17 include several other sources.

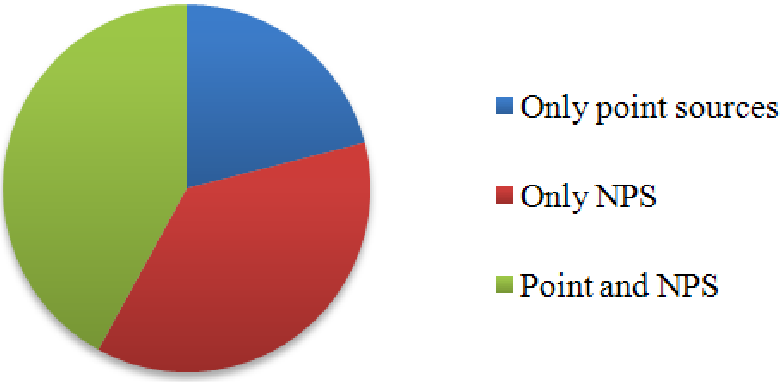

Figure 8: Different pollutant sources considered in the literature sample

Analyzing the different methodologies used for assessment of water quality (Figure 9), it is concluded that 48 references used field monitoring, 11 references used statistic methods, and 17 references used modeling approach.

Particularly worth mentioning is that the most used statistic methods are Principal Component Analysis (PCA) account for 5 papers, Cluster Analysis (CA) have 3 papers and Factor Analysis (FA) occupied 2 papers. The most used modeling tool is the soil and water assessment tool (SWAT), accounting for 3 papers and the mass balance model was mentioned in 2 papers.

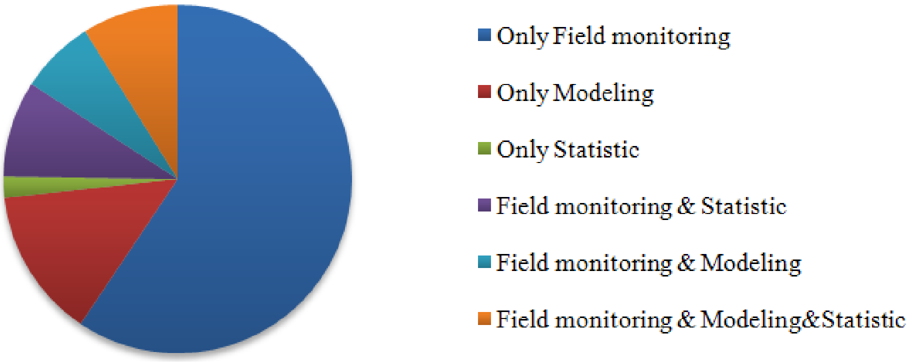

Figure 9: Different methodologies used in the literature sample

4. Water quality issues in different Asian countries

4.1 Rainfall distribution and population density in China

Increasing rainfall variability as a consequence of climate change can influence watershed biogeochemical processes and surface water quality through complex interactions between hydrology and biogeochemical processes, including the production, release, and transport of natural materials and anthropogenic pollutants [85]. It is important to understand the distribution of precipitation in China, the country in this study that will be analyzed with more detail because of both the literature research result and the nationality of the author of this work.

As can be seen from Figure 10, the average annual precipitation of China in 2004 was 590.6 mm, 22.1 mm less than the historical average. In regions such as the Southeast part of North China, lower reaches of the Yellow River, most parts to the South of the Weihe River, the annual precipitation was over 500 mm. Among them, the middle and lower reaches of the Yangtze River, most of the region to its South bank and some areas of the Eastern part of Southwest China received 1000 mm ~ 2000 mm of precipitation. As for the remaining of China, the precipitation was less than 500 mm.

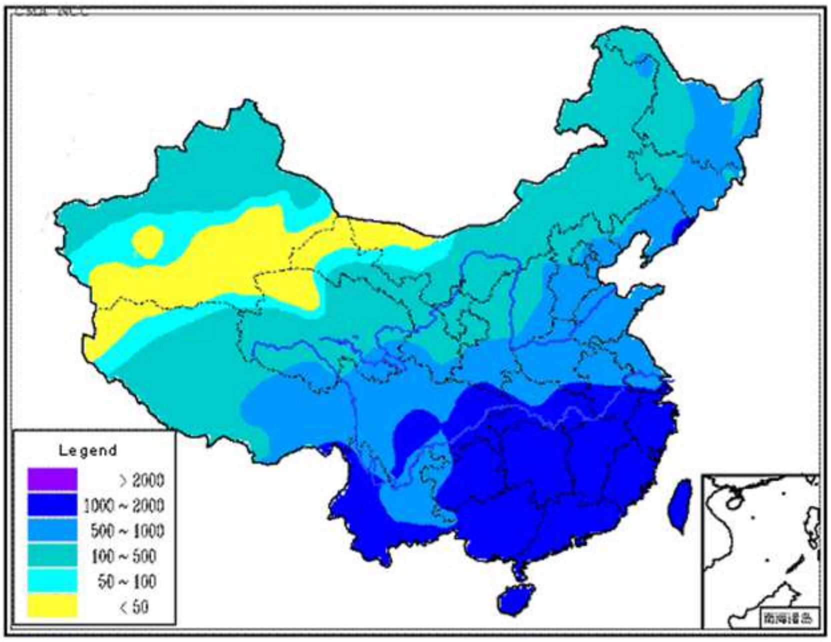

Figure 10: Distribution of precipitation in China in 2004 (in mm) [86]

Usually the presence of human settlements means more pollution. As one can see from Figure 11, the highest population density is in the mega cities such as Shanghai, Beijing, Shandong and Henan, where the population density in these provinces is around 300 people per km^2. Population density of Ningxia, Yunnan, Heilongjiang, Gansu, Inner Mongolia, Xinjiang, Qinghai and Tibet is lower than the average of the country. Thus, the population density in coastal regions in East China is higher and in the Central and West China regions, the population becomes scarce.

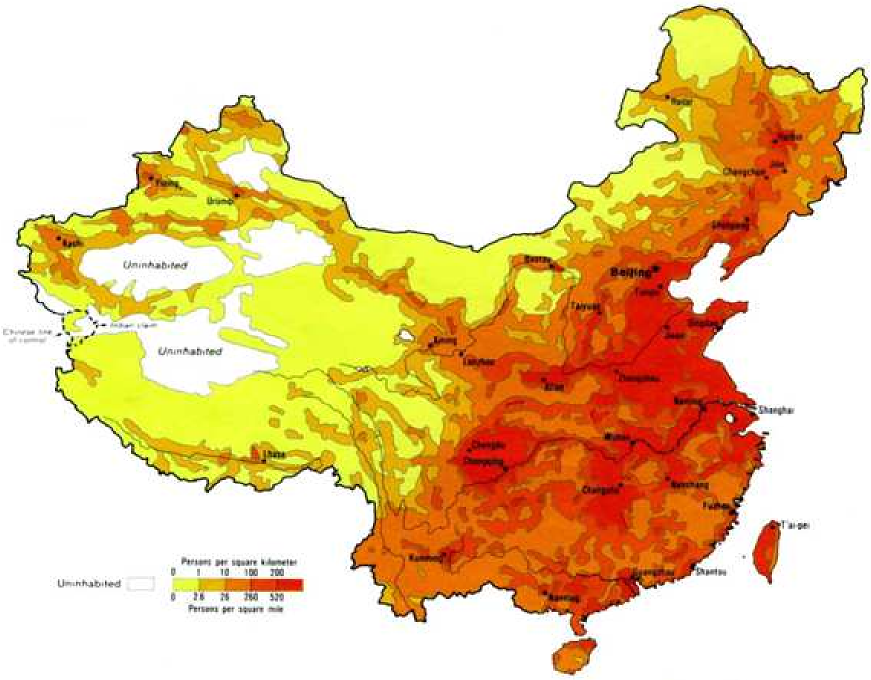

Figure 11: Population density in China [86]

To sum up, in the Southeast of China there are more inhabitants and higher rainfall volume, in the Northwest there are less population and less rainfall; on the other hand, the distribution of freshwater resources is highly unbalanced in China. Northwest China accounts for 64% of the national territory, but provides only 19% of the country’s available water resources. Conversely, Southeast China possesses 81% of the total national water resource [35]. Because of these differences, the water quality situation in China will be made considering two different regions in the country, the Southeast and the Northwest.

4.2 Water quality issues in the Southeast of China

4.2.1 Three Gorges Reservoir (TGR) region

The Three Gorges Reservoir (TGR) region of the Yangtze River of China, which is located in the South of Qinlin Mountain and Dabashan Mountain, covering the cities and the counties of Yichang, Zigui, Badong, Wushan, Fengjie, Wanzhou, Fuling, Changshou and Chongqing, is known as the largest hydropower project in the world. It covers an area of 59,900 km^2 and a population of 16 million (Figure 12). The TGR region is important for agricultural and other economic activities such as water supply, fishing and livestock production [32].

NPS pollution is the dominate water quality problem in the Hubei Province of TGR region. In 2008, 140.7 kt of chemical fertilizers was used for farming in this region, of which 12.54 kt were estimated to be incorporated in the runoff. In that year, the slaughter houses in this region processed 2.69 million pigs, 0.2 million big livestock, and 13 million poultry. It was estimated that 8445 kt of livestock manure was generated in TGR region in 2008 [88]. In addition, soil erosion, as a result of converting forest into agriculture, exerted negative impacts on agricultural land and the TGR region, including water quality problems such as eutrophication.

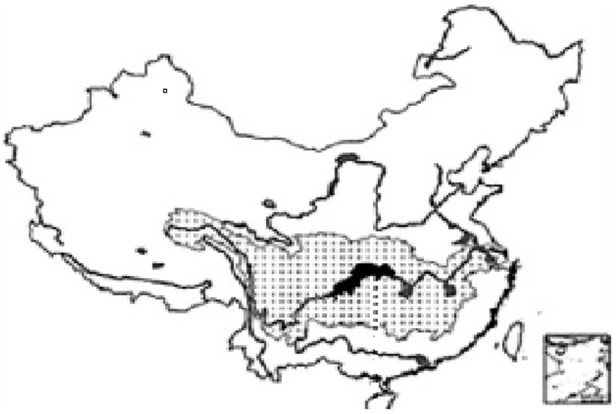

Figure 12: Location of TGR region in China. Adapted from [32]

The eutrophication of lakes and reservoirs has become one of the most severe problems in China for decades. The atmospheric deposition is the dominant NPS of total nitrogen (TN) while the major part of total phosphorus (TP) pollution is from land use. NPS includes nutrient salts, pesticides and other contaminants from agricultural fields, in which N and P are transported to surface water and water bodies under the action of rainfall and irrigation, along with water and soil erosion, by means of surface runoff, subsurface flow, and farm drainage. These nutrients can induce eutrophication in the receiving waters and loss of biodiversity in the aquatic ecosystem. Paper [32] indicats that the potential TN load was much higher than the potential TP load. The calculated TN load was 2.83×10^4 tones, while the TP load was 2.14×10^3 tones in 2007.

Paper [38] discusses the occurrence of antibacterial agents in the aquatic environment of Chongqing region of the TGR (Figure 13). In this area, the concentration of antibiotics was mainly below the quantification. Hospitals, nurseries and slaughter houses were the main source of antibiotics in the river. Antibiotics are only partially eliminated in sewage treatment plants and the residual antibiotics may be discharged into environment and contaminated drinking water. The concentrations of antibiotics in Chongqing region of the TGR were below the limit of quantification. Jialing River was more contaminated by antibiotics than the Yangtze River possibly due to presence of more hospitals located in the river basin [38].

4.2.2 Jilin

The Shitoukoumen Reservoir is located in Jiutai City, Jilin Province. It covers an area of 4,944 km^2 (Figure 14). The Shitoukoumen reservoir catchment lies in the North Temperate Zone, where the annual rainfall is 369.9-667.9 mm, mainly concentrated from May to September. Annual average evaporation is 1,658 mm, thus the balance is negative and there are often drought and serious water shortages.

Figure 13: Rivers distribution in the Chongqing region of the TGR. Adapted from [38]

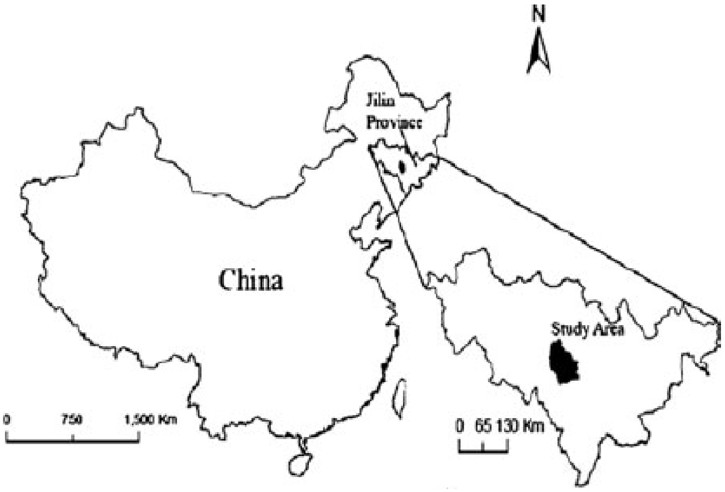

Figure 14: Location of Shitoukoumen reservoir catchment in the Jilin Province. Adapted from [22]

In recent years, the water quality of Shitoukoumen reservoir has deteriorated because of NPS pollutants from upstream, from sources such as pesticides, fertilizers, urban sewage, rural domestic garbage, wastewater from industrial and mining enterprises in protected areas, and soil erosion. The annual NH_4^+-N load into Shitoukoumen reservoir shows a significant downward trend with a decrease rate of 40.6 t per decade. The annual TP load shows an insignificant increasing trend, and its change rate is 3.77 t per decade. The deterioration of water quality poses a serious threat to the safety of drinking water for residents [22].

4.2.3 Zhejiang

The Qiantang River is the largest and longest (484 km) river system in Zhejiang Province (Figure 15). Qiantang River is the main source of drinking water for the population of this region. It also supplies water for industrial and agricultural activities in areas close to the river channel. In the last 10 years, the economy in the Qiantang River basin has developed rapidly and the living standards of the local population have improved markedly. Increasing pollution from point source and NPS has caused a considerable degradation of water resources and had a negative impact on human population health [20].

Table 3 shows the mean concentration of measured parameters in Qiantang River. The authors of paper [20] categorized the monitoring data into three major pollution zones (low, moderate, and high) based on national quality standards for surface waters. Most sites classified as 'low pollution zones' occurred in the main river channel, whereas those classified as 'moderate and high pollution zones' occurred in the tributaries.

Figure 15: Location map of Qiantang River basin. Adapted from [20]

Table 3: Mean concentration of measured variables in Qiantang River. Adapted from [20]

	NH_3-N	**F^-**	**COD_{Mn}**	**Cr^{6+}**	**DO**	**BOD_5**
Mean concentration	1.376	0.583	3.982	0.005	6.614	2.534
	V-ArOH	**Petroleum**	**TCd**	**T-CN^-**	**TP**	**TPb**
Mean concentration	0.003	0.063	0.001	0.003	0.134	0.015

In low pollution zones, NPS pollution such as agricultural runoff and urban runoff dominated; in moderate pollution zones and high pollution zones, mixed source pollution dominated. The pollution in the small tributaries was more serious than that in the main channel. At most high pollution zones sites, there were many factories and the chemical measured values were very high. TP was mainly from domestic sewage of residential areas and tertiary industries, such as tourism, and the food and beverage industry. Runoff from farms after applying phosphate fertilizer was also an important source of TP. F^- , COD_{Mn}, V-ArOH and BOD_5 [20].

4.2.4 Guangzhou

The Beijiang River is the source water of drinking for over a million people and is a tributary of the Pearl River that flows mainly through the North of Guangzhou (Figure 16). The industrial/urban area in the catchment has a population of approximately 1.26 million, most of them live in two towns: Qingyuan City and Qingxin County (as Figure 13 shows, I & II); both are rapidly expanding. Traditionally, industries in the catchment were dominated by building materials, electronics, metallurgy, and nonferrous metals. The rapid growth of the industries promoted local economic development, but unfortunately polluted the water reservoirs [41].

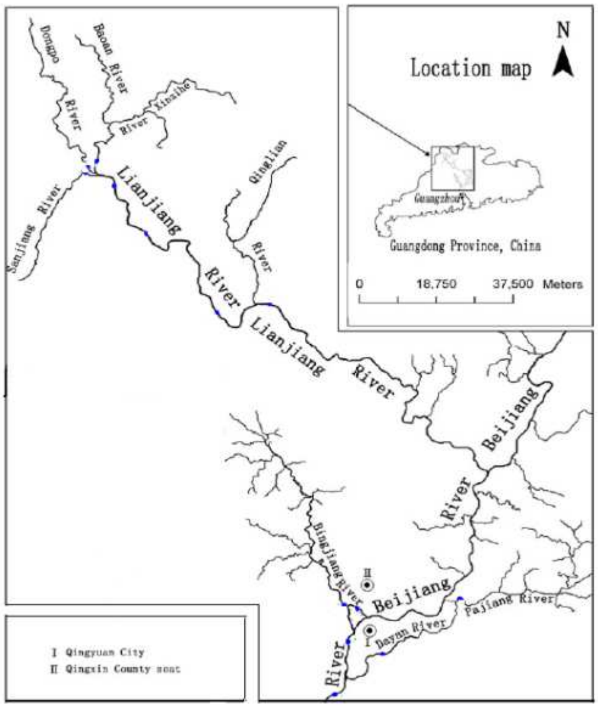

Figure 16: Location map of the Beijiang River Basin. Adapted from [41]

With both industrial and urban sources located at the lower catchment of Beijiang River, the river water was enriched in NH_4, TN, COD_{Mn}, and most of the trace elements, with the highest concentrations of NH_4, TN, major ions, and trace elements being found in Dayan River (Table 4). The pH became relatively low due to the inflow of industrial and urban wastewater [41].

4.2.5 Hainan

The Songtao reservoir is regarded as the most important water source system at the Chinese Hainan Island (Figure 17). The Songtao Reservoir was constructed in 1969 and has a 2.9 billion m^3 capacity. The climate in this region is a tropical monsoon marine climate with an average annual precipitation of 1896 mm. Most of the rainfall occurs from May to August. The land use is mainly agriculture and forestry. The reservoir experienced a continuing decrease in water quality, attributed mainly to agricultural NPS pollution. The model (EcoHAT) simulated the NO_3-N, NH_4^+-N, and P concentrations in the runoff for the Songtao watershed with considerable accuracy [35].

Table 4: Average, minimum, and maximum values for Dayan River on the industrial/urban area. Adapted from [41]

Parameter	**pH**	**DO (mg l^{-1})**	**COD_{Mn} (mg l^{-1})**	**COD_{Cr} (mg l^{-1})**	**BOD (mg l^{-1})**	**NH_4 (mg l^{-1})**
Mean	6.82	4.08	5.83	26.93	7.557	5.207
Range	4.73–7.47	0.01–7.03	2.13–28.20	11.60–97.20	1.400–47.600	0.904–10.623
	TN (mg l^{-1})	**PO (mg l^{-1})**	**VP (µg l^{-1})**	**CN (µg l^{-1})**	**Cu (µg l^{-1})**	**Zn (µg l^{-1})**
Mean	6.51	0.026	2.40	4.27	104.51	219.53
Range	1.72–14.11	0.010–0.060	1.00–5.00	4.00–6.00	8.70–242.00	50.00–683.00
	Cr (µg l^{-1})	**Pb (µg l^{-1})**	**As**	**Cd (µg l^{-1})**	**TP (mg l^{-1})**	
Mean	21.40	6.80	18.60	1.33	0.18	
Range	7.00–99.00	1.00–20.00	0.50–38.00	0.10–5.70	0.03–0.91	

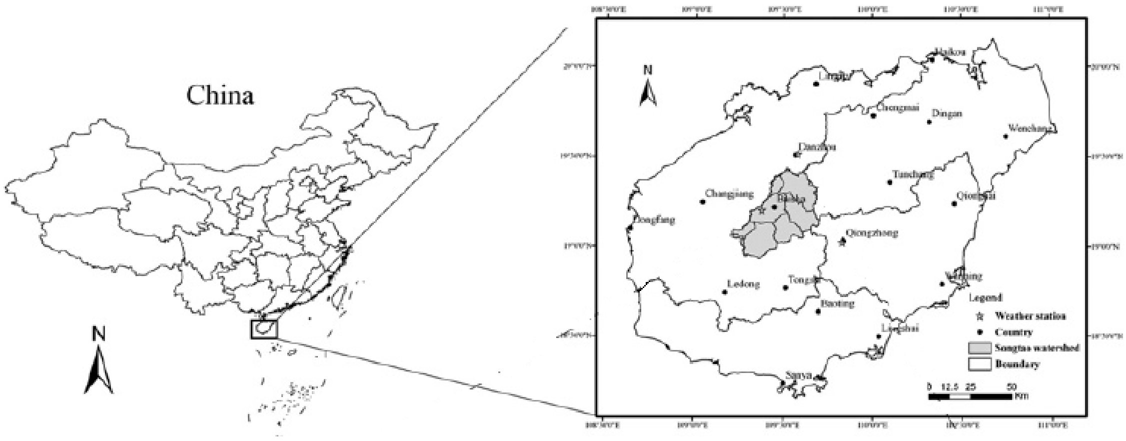

Figure 17: Location map of Songtao reservoir watershed in Hainan Island. Adapted from [36]

Lastly, the authors of paper [36] simulated the effects of the change in land cover and management practices in several specific scenarios on the local watershed's nutrient transport. The scenario analysis revealed that with 40% reduction of fertilization, a 7.51% of TN load, and a 7.76% reduction of TP load could be achieved. Conservation measures were more effective in the study area in the purpose of reducing sediment loads.

4.2.6 Hong Kong

Hong Kong lies to the South of Guangdong province, China. The South Western New Territories and Kowloon area runs from the West of Tuen Mun to the East side of Kowloon and covers Western Buffer, Victoria Harbor, and North Western Water Control Zones (Figure 18).

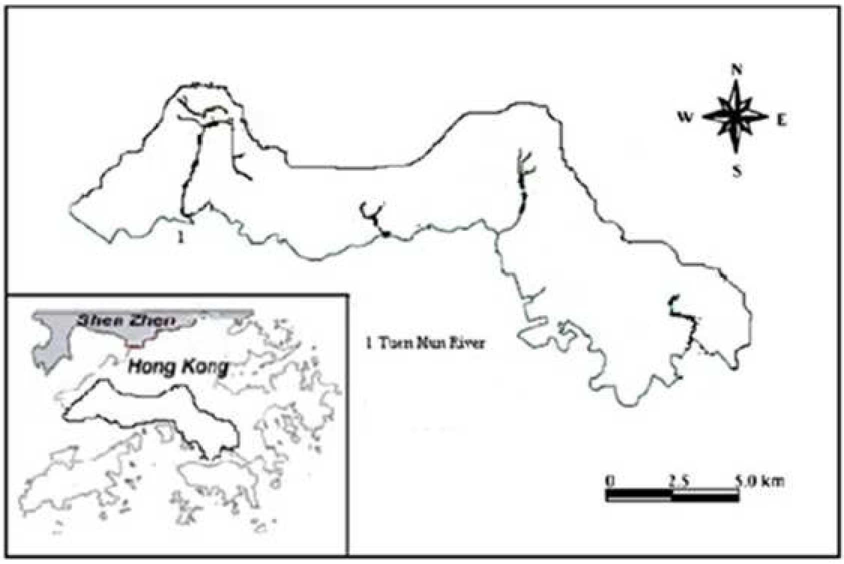

Figure 18: Location map of Honkong. Adapted from [30]

The basic statistics of the 8-year data set on water quality of Tuen Mun River are summarized in Table 5. The authors of the paper [31] concluded that Kai Tak Nullah was greatly affected by organic pollution, industrial pollution, and NPS pollution. The main pollution source in the North of Tuen Mun River is NPS pollution with organic matter, while industrial pollution had high effect on the South of Tuen Mun River.

Table 5: Average, minimum, and maximum values for Dayan River. Adapted from [41]

Parameters	**Unit**	**Max**	**Min**	**Mean**
DO	mg/l	11.90	1.20	7.16
Turbidity	NTU	1,454.60	0.10	18.66
ES	µs/cm	46,410.00	43.00	11,623.14
TSS	mg/l	2,100.00	0.50	26.24
TS	mg/l	61,000.00	34.00	8,811.62
BOD_5	mg/l	210.00	0.10	8.54
COD	mg/l	540.00	2.00	20.73
F.coli	cfu/100 ml	31,000,000	1.0	517,598
E.coli	Cfu/100 ml	9,200,000	1.0	138,912
NH_4^+-N	mg/l	17.00	0.005	1.59
NO_3^--N	mg/l	7.90	0.002	1.794
TKN	mg/l	65.00	0.06	2.532
TP	mg/l	61.00	0.06	0.716
Cr	µg/l	43.00	1.00	1.872
Pb	µg/l	290.00	1.00	4.634
Ni	µg/l	50.00	1.00	3.498
Mn	µg/l	2,700	10.00	142.987
Fe	µg/l	26,000	50.00	366.69
AS	mg/l	6.40	0.05	0.361
F	mg/l	2.60	0.20	0.574
Zn	µg/l	1,300.00	10.00	42.80

4.2.7 Taiwan

a) Southern Taiwan

The Gao-ping River is one of the most important rivers for water supply and irrigation in Southern Taiwan. It has a total length of 171 km with a catchment basin of 3257 km^2, which is the largest catchment basin in Taiwan (Figure 19).

Gao-ping River is also one of the most contaminated rivers in Taiwan. Approximately 500,000 tons of industrial and domestic wastewater, mainly from husbandry wastewater, is discharged daily into the river. Two petrochemical industrial parks are located near the mouth of the estuary and discharge 16,000 tons of wastewater daily into the river. Moreover, Gao-ping River has been historically subjected to severe anthropogenic inputs of pollutants, such as heavy metals, TN, TP and BOD_5. No measurement has been made of the content and composition of PAHs in Gao-ping River, nevertheless high contents of PAHs were found in the estuary of the river and in the vicinity of industrial areas. Concentrations of the total 16 PAHs (∑PAHs) in river water ranged from below detection limits (＜MDLs) to 9.4 µg /L with the mean value of 0.43±0.75 µg/L (n= 48), which were predominated by two- and three- ring PAHs. The petrogenic PAHs may be mainly originated from the leakage of crude oil and the refined products from urban vehicle traffic, while the pyrolytic PAHs input is located in the proximity near the mouth of the estuary of the

River [33].

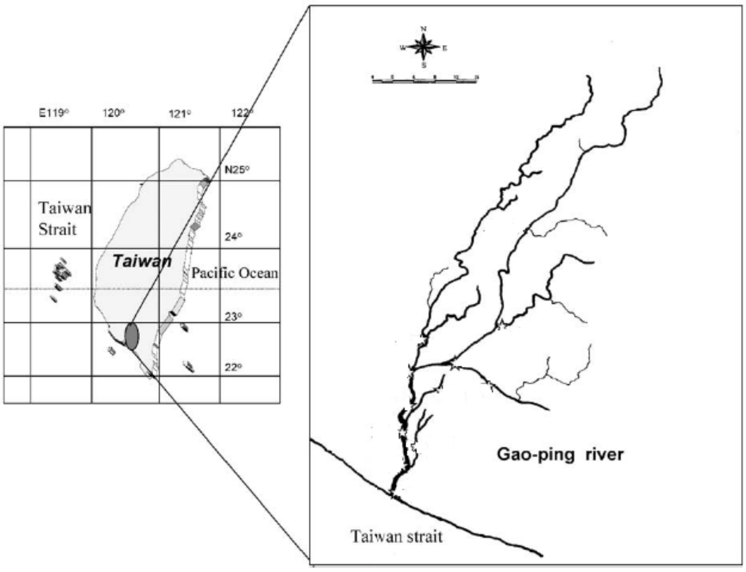

Figure 19: Location map of Gao-ping River in Taiwan. Adapted from [33]

b) Northern Taiwan

The Feitsui Reservoir is in the North of Taiwan (Figure 20) and it’s the source of domestic water supply for the Taipei Metropolitan Area, which has a population of over five million. The storage capacity of the reservoir is 406 million m^3. The mean annual precipitation rate in this area is approximately of 2500 mm.

In the Northwest of the reservoir, there are two municipal wastes incinerators about 15 km from the reservoir. Those two incinerators could be the possible emission sources of PCDD/Fs (classified as POPs) in the vicinity of the Feitsui Reservoir. The atmospheric PCDD/F toxicity equivalent (TEQ) concentration measured in the vicinity of the reservoir ranged from 4.9 to 39 fg I-TEQ m^{-3} (1 fg = 1×10^{-9} mg) and the Asian dust storm in February (it happens almost every year in February) accounted for the peak value, which corresponded to a total suspended particle concentration of 128µg m^{-3}. The atmospheric PCDD/F deposition ranged from 1.4 to 19 pg I-TEQ m^{-2} d^{-1}, with higher deposition occurring during winter and spring. During summer, when atmospheric deposition is lower, typhoons bring heavy rainfall that enhances soil erosion and creates turbidity-driven intermediate flow. This result is significantly higher PCDD/F deposition in water column of the reservoir at 70 m water depth (179 pg I-TEQ m^{-2} d^{-1}) than at 20 m (21 pg I-TEQ m^{-2} d^{-1}) during typhoon events.

The authors of the paper established a mass balance between the measurements of atmospheric deposition and sinking particles in the water column, which revealed that around 54-74% of PCDD/F inputs into the reservoir, were a contribution from the catchment erosion during normal period. However, the PCDD/F input from the enhanced catchment erosion significantly increased to 90% during intensive typhoon events [37].

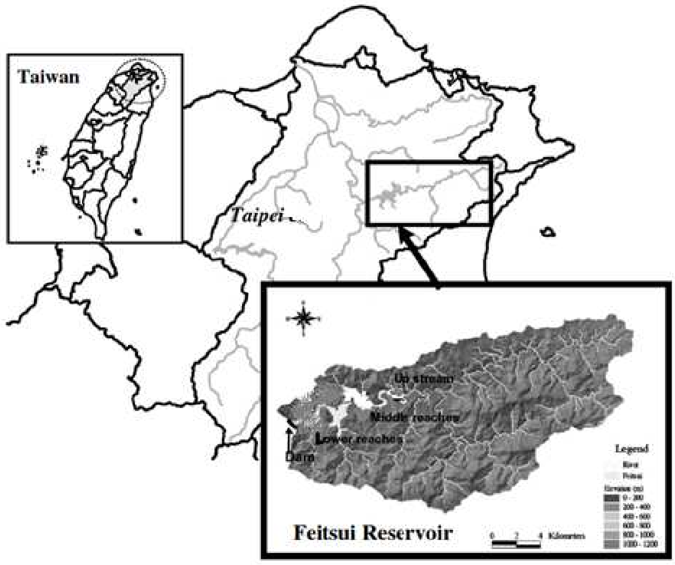

Figure 20: Scope of the catchment area of the Feitsui Reservoir situated in northern Taiwan. Adapted from [37]

4.3 Water quality issues in the Northwest of China

The Wuwei basin, which is located in the Eastern part of the Hexi Corridor near Lanzhou, Qinghai, and Inner Mongolia, is an eco-zone that links the Loess Plateau, Tibetan Plateau, and Mongolia-Xinjiang Plateau. The Shiyang River starts in the Qilian Mountains, with a catchment area of 4.16 $\times 10^4$ km^2 and total length of nearly 300 km.

The river water in the mountain is of good quality with the TDS below 500 mg/l. However, the organic pollutants, including COD, BOD, NH_4^+-N, TP and phenol, followed sharply increasing trends from Wuwei city to Hongya reservoir. Sharp increases in population and economic development in Wuwei basin mean that human activity has become an important agent that affects surface water quality directly and indirectly, leading to imbalances in the chemical composition of this water. The substances released included industrial wastes, domestic sewage, rubbish, organic and inorganic fertilizers, and pesticides, which include a range of substances that are harmful to humans and the ecosystem. These pollutants are discharged into surface waters in various ways, leading to the deterioration of the water quality [40].

4.4 Characteristics and present situation of water resources in Japan

4.4.1 Rivers

The analyses of papers [44] and [47] revealed similar water quality issues, since both study heavy metals (metals are having a density of 5g/cc) such as As, Cu and Zn. It is worth reminding that heavy metals in surface water systems can came from natural or anthropogenic sources and the watershed topographic features can play an important role in modulating the quality of water.

Paper [44] revealed that the concentration of cations and heavy metals in mountainous stream waters may be strongly related to geological factors. In most mountainous stream waters, Cd, Pb, Zn, Cu and As were found in low concentrations (less than 0.5 μg/l), the concentrations of Al were less than 50 μg/l, and no Al concentrations of more than 300 μg/l was found in the river.

The authors of paper [47] found that the concentrations of heavy metals in Ichi-Kawa River (Figure 21) were distinctly higher because of mine drainage. The average concentrations of Cd, Pb, and As were below the Environmental Quality Standards established in 1971 (Cd = 10 μg/l; Pb = 100 μg/l; As = 50 μg/l). Moreover, the metal concentrations, especially those for As, were sometimes much higher than the present revised standards established in 1993 (Cd, Pb and As = 10 μg/l). Environmental standards for copper and zinc were not established, and these metals have been controlled only by effluent standards in Japan.

Figure 21: Location of Ichi-Kawa River. Adapted from [47]

Papers [45] and [53], concern water quality issues of TP, TN, SS. The Hii River basin is located in the Eastern part of Shimane Prefecture (Figure 22), Japan, and has an area of approximately 920 km^2. Approximately 81.6% of the watershed is forest, 10.5% is occupied by paddy fields, 2.6% is devoted to upland crops, and 2.0% is residential area.

SWAT was applied to the Hii River basin with a daily time step, and simulated flow, SS, TN, and TP load discharges from 1988 to 2009 [44]. Annual average discharges of the loads from Otsu (site 1 in Figure 21) to the downstream reach were 27.4 tons km^{-2} for SS, 1052.6 kg km^{-2} for TN, and 43.3 kg km^{-2} for TP. Most of these discharges are considered to flow into Lake Shinji, though some may be adsorbed or deposited on the river bed during the 10 km transport distance from the Otsu gauge site to the lake. In the Hii River watershed forests were the largest contributor of SS, TN, and TP in the basin, it accounts for 63% (SS) and 48% (TN) of the discharges. Upland fields had the second largest impact on these loads in the basin, because fertilizer applied to the fields is a major source of N and P.

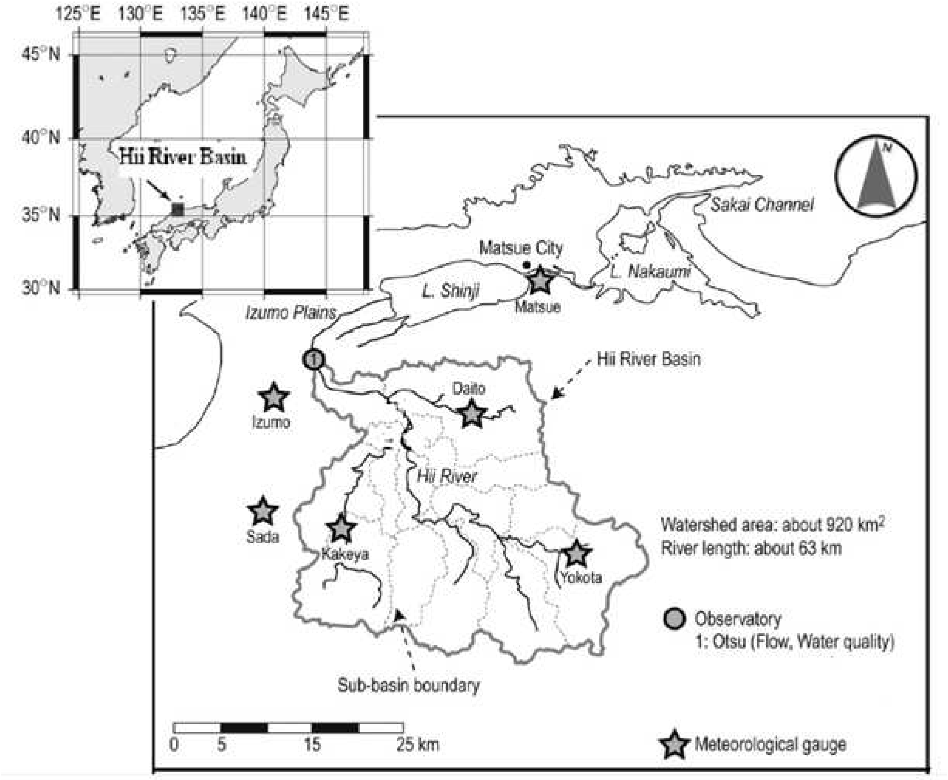

Figure 22: Location of Hii River basin. Adapted from [45]

Yodo River (Figure 23) is the main river flowing and a major source of drinking water for more than 11 million people of Kansai region in Japan. Perfluorinated compounds (PFCs) in the environment have persistent, bioaccumulation, and potentially toxic effects.

PFCs were detected in higher concentration even exceeding more than 1000 ng/l in some part of Yodo River. Although the discharge of PFCs from wastewater effluents upstream could be one of the major point sources, the concentrations did not exceed 29.4 ng/l downstream of the river, possibly due to dilution effects. Daily mass load of main PFCs downstream of the Yodo River was estimated to be 451.7 g/day, of which nearly 30% was contributed by WWTP effluents. Results of paper [49] showed that Yodo River system could have a unique upstream-downstream linkage of PFCs contamination and the river could be a continuous pathway of PFCs exposure to the people of Kansai region.

According to the authors, the lack of an efficient removal method on these compounds and large scale uses of PFCs will continue in the future due to the absence of appropriate alternatives to replace them, as a result, PFCs will be constantly released into the water environment through different point and NPS.

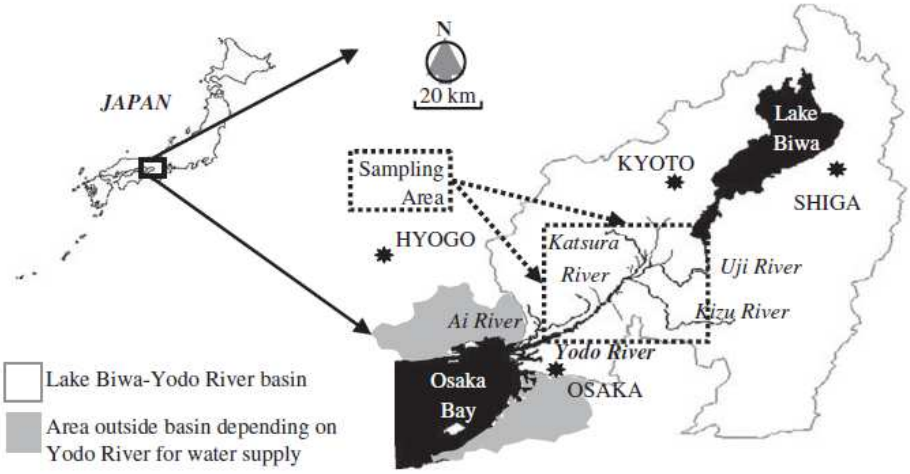

Figure 23: Map of Yodo River basin [49]

Ayase River (Figure 24) is one of the most polluted rivers in Japan by PCDDs, PCDFs and dioxin-like PCBs. The Toxicity Equivalency (TEQs) ranged from 0.26 to 7.0 pg-TEQ/l (1 pg = 1×10^{-6} mg), with an average of 2.7 pg-TEQ/l. The TEQ value was high during the irrigation period from May to August. Most of the dioxins in the river water are associated to the suspended solids (SS) and it seemed that the river received high-dioxin contaminated SS during the irrigation period. The dioxins in the river were affected by pentachlorophenol (PCP) and chlornitrofen (CNP) formulations which were widely used as herbicides for a large area of paddy fields, existing at the upper part of the river basin [52].

Figure 24: Location map of Ayase River

4.4.2 Lakes

According to the literature gathered in this study, it was found that most water quality issues in Japanese lakes concern TP, TN, COD.

For example, Lake Biwa (Figure 25) is the largest lake in Japan and used as a drinking water resource by 14 million people in Western Japan. Pollutants discharged into Lake Biwa through inflowing rivers and streams are considered to have a great influence on water quality. The ratio for rice paddy fields in Lake Biwa basin is 23%, and the runoff water from the rice paddy fields is known to contain high concentrations of TN and TP. The authors of paper [42] established a mass balance model for runoff water and N in the basin. As a result of calculations, the annual runoff loads into the Akanoi Bay were estimated to be 113t/y for TN and 19.5t/y for TP. In present days, the rice paddy fields are considered to be one of the largest pollutant sources for agricultural runoff.

Figure 25: Location map of Lake Biwa (site A)

Another lake named Inba has similar water pollution problems. Lake Inba (Figure 26) is one of the most eutrophic lakes in Japan. This lake is an important water source for agriculture, industry, and drinking water supply in the Chiba Prefecture. Yet, the water quality of Lake Inba remains low, with high COD, TP, and TN levels in the range of eutrophic lakes. In 2009, the average COD was 8.6 mg/l, TN concentration was 2.7 mg/l, and TP concentration was 0.11 mg/l. In 2009, the dominant phytoplankton species were the diatoms *Aulacoseira ambigua* from May to July and *Aulacoseira granulata* from September to November. In August, the *cyanobacterium Microcystis aeruginosa* was the dominant species [50].

Figure 26: Location map of Lake Inba (site A)

4.4.3 Reservoirs

Kirishima City is located in the Northern part of Kagoshima Bay in Southern Japan (Figure 27), where rice is cultivated in paddy fields situated near the sea. Japan is one of the highest consumers of pesticides, particularly herbicides in the world. As previously reported, during the rice planting seasons of 2004 and 2005, several pesticides were detected in freshwater areas of Kirishima City that are adjacent to paddy fields, especially the wastewater reservoir located near the sea. The maximum concentration of mefenacet, of 4.22 µg/l, was at least one magnitude higher than that of fenobucarb and iprobenfos, of 0.27 and 0.19 µg/l, respectively, while flutolanil phthalide, pyriproxyfen had concentrations just around the detection limit of 0.01 µg/l. Rice cultivation, especially in low-lying paddy fields, is inherently risky to the environment and easily become a NPS of pollution since paddy water normally flows out into the surrounding bodies of water [51].

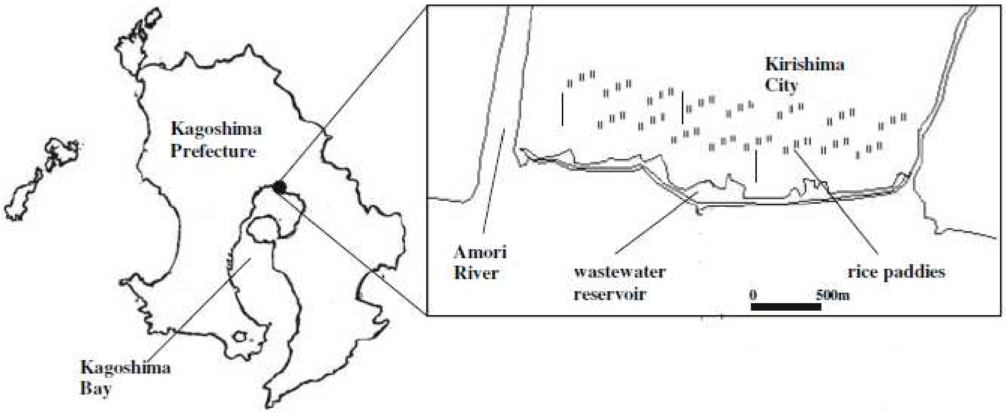

Figure 27: Map of the study area. Adapted from [38]

4.5 Characteristics and present situation of water resources in India

4.5.1 Rivers

According to the collected literature [54], [55], [57], [58], [59], [62], [63] and [64], all these studies analyzed the heavy metals: Cd, Cr, Cu, Fe, Mn, Zn, Pb and some organic pollutants.

Two references [55] and [58], focused on the water quality problem caused by heavy metals such as Cr, Cu, Fe, Mn, Zn and Pb. Ghaziabad is situated in the middle of the Ganga-Yamuna alluvial land and is the fastest growing industrial city of the State. It is located about 1.5 km east of the Hindon River (Figure 28). The annual mean rainfall in this region is 702mm.

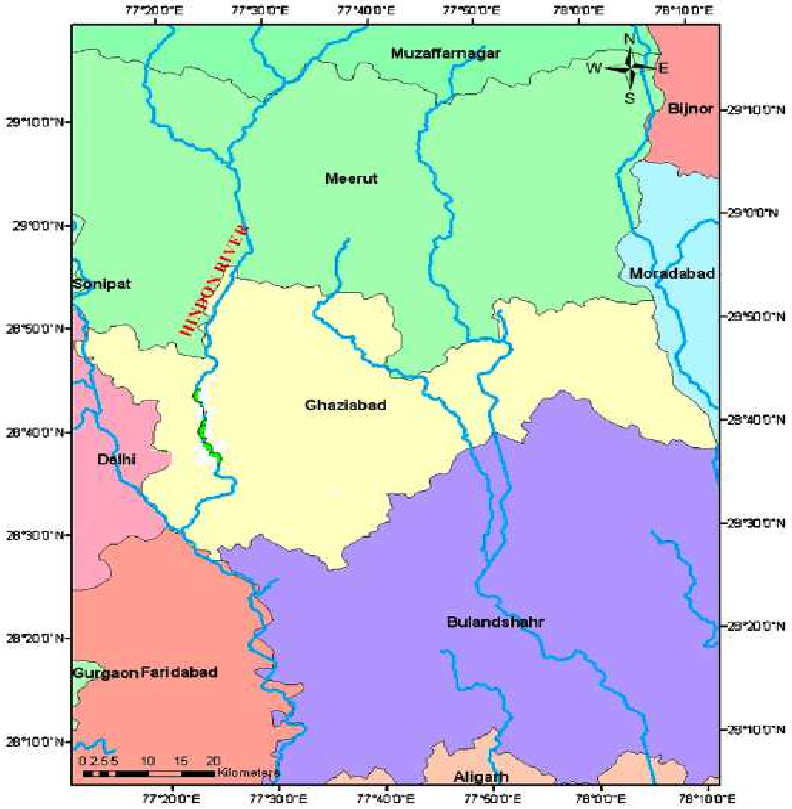

Figure 28: The location map of Hindon River in the map of Ghaziabad, India. Adapted from [55]

The concentration of metals in the river water showed wide variations sometimes below detection limit (BDL) with Cd, 2.40-24.1µg/l; Cu, BDL-4372.5 µg/l; Cr, 31.2-330.9 µg/l; Fe, BDL-1247.4 µg/l; Mn, 1.70-867.5 µg/l; Zn, 0.501-836.4 µg/l and Pb, 30.1-902.1 µg/l. The geoaccumulation index (I_{geo}) indicates that River Hindon is moderately polluted with Cu, Cr, Fe ($I_{geo} < 2$), unpolluted to moderately polluted with Mn, Pb and Zn ($I_{geo} < 1$), and very strong polluted with Cd ($I_{geo} > 5$).The industrial and urban discharges located within the river catchment areas were the major sources of heavy metals [55].

The Kabini River, a confluence of the tributaries from Panamaram and Mananthavady area originates from the Western Ghats, in the Wynad district of Kerala, passes through the Nanjangud industrial area, flows into the main river Cauvery with its confluence of downstream T.Narasipura.

The River Kabini in Karnataka (Figure 29) carries natural and anthropogenic pollutants, mainly heavy metals released from industrial effluents, agricultural return flows and domestic sewage. Concentrations of Cu, Cr, Mg, Fe, Mn, Ca, Na, K and Zn in water are shown in Table 6. It should be pointed out that Ca and Fe show the highest concentrations [58].

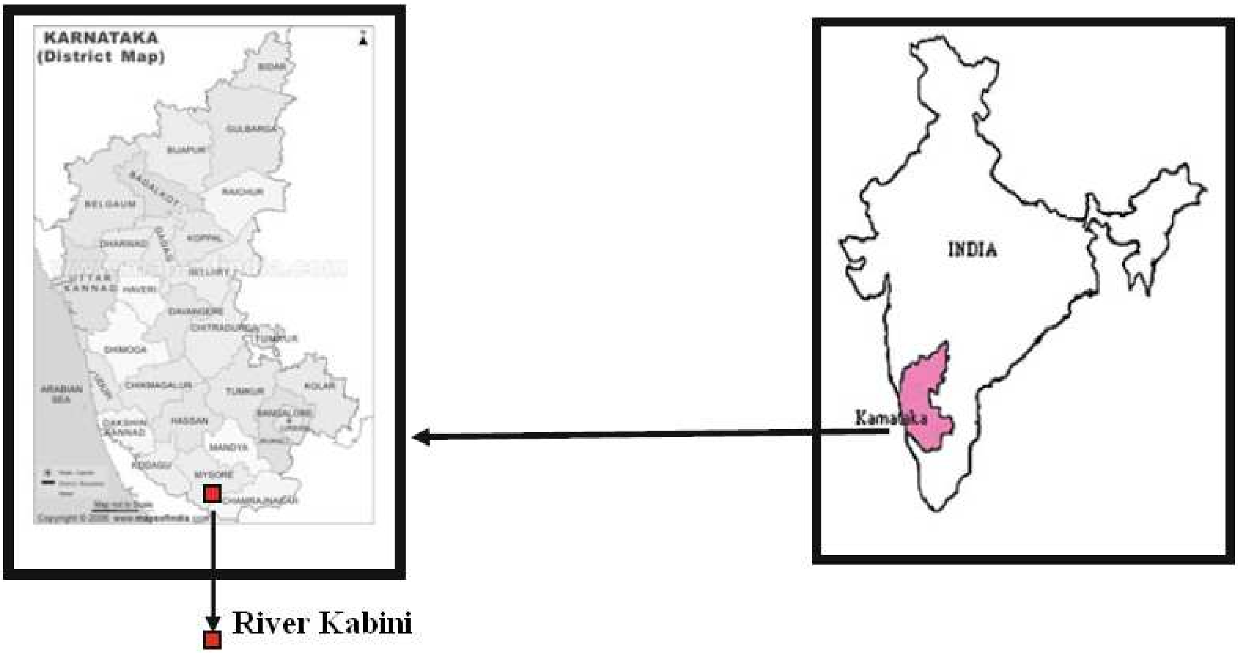

Figure 29: The location map of River Kabini in the map of Karntaka, India. Adapted from [55]

Table 6: Min, Max and Mean concentration of metals in the Kabini River water. Adapted from [58]

Concentration (mg/lit)	**Cr**	**Cu**	**Fe**	**Zn**	**Mn**	**Ca**	**Mg**	**Na**	**K**
Min	8.90	16.70	36.33	20.33	1.66	60.00	40.00	10.46	1.43
Max	39.96	45.93	97.83	132.50	35.70	150.66	88.33	34.83	3.46
Mean	21.80	27.44	63.55	53.95	21.71	87.96	55.82	21.24	2.411

The Manimala River (Figure 30) is one of the important rivers in Kerala with a length of around 90 km and a catchment area of about 847 km^2. The river is the major drinking water source in this region. But, the fast pace of urbanization, industrialization, fertilizer used in intensive agricultural activities and rise in pilgrim tourism in the past four to five decades have imposed marked changes in water quality parameters (pH, electrical conductivity, dissolved oxygen, total dissolved solids, Ca, Mg, Na, K, Fe, HCO_3, NO_2-N, NO_3-N, P-inorg, P-tot, chloride, SO_4, and SiO_2). Except for NO_3-N and SiO_2, all the other parameters are generally higher during the non-monsoon months (December-May) compared to that of monsoon months (June-November). The flux estimation reveals that the Manimala river transports an amount of 2,308 t y^{-1} of dissolved inorganic N, 87 t y^{-1} dissolved inorganic P, and 9246 t y^{-1} of SO_4, and 1984 t y^{-1} of K into the receiving coastal waters. These alltogether constitute about 23% of the total dissolved fluxes transported by the Manimala River. The problems are increased due to leaching of ionic constituents from the organic-rich impervious sub-surface layers that are exposed due to channel incision resulting from instream mining [62].

Figure 30: Location map of Manimala River Basin in India. Adapted from [62]

4.5.2 Lakes

Kolleru Lake (Figure 31) is a freshwater lake in South Eastern India with a high potential for aquaculture. Various chemicals such as pesticides are used to control diseases and ectoparasites in intensive aquaculture farms in India. The input of chemicals such as pesticides in intensive aquaculture may cause the accumulation of pesticides in fish tissues from the sediment and water from fish farms. The pesticides levels in fish are higher than the standards for human consumption. The lake quality is deteriorating daily owing to aquaculture practices in the lake region, besides other activities [60].

Carambolim Lake (Figure 32) is a man-made wetland with an area of 70 ha. It is the main source of water for irrigation for the agricultural lowland in the Karmali area. The study concluded that the aquatic macrophytes probably play a major role in reducing the effect of high concentrations of heavy metals, therefore, the macrophyte community of the Lake area is needed, and should be protected and restored, as a priority. Of the 14 metals investigated, 9 (Ca, Fe, Al, Cr, Cu, Ba, Ti, Co and Pb) showed higher rates of accumulation in the root whereas 3 (Mn, Zn and Mg) showed more accumulation in stem and 1 (Ca) showed higher accumulation in the leaves. In most of the samples Cu was accumulated more in the roots (50±47.15 μg/g) and less in flowers (9.52±3.97 μg/g). Occurrence of heavy metal was much higher in macrophytes of Sevan Lake than that of the Carambolim Lake. The accumulation of 14 elements was in order of Ca>Mg>Fe>Al>Mn>Ba>Zn>Ti>Cu>Cr>Co>Ni>Pb>Cd [61].

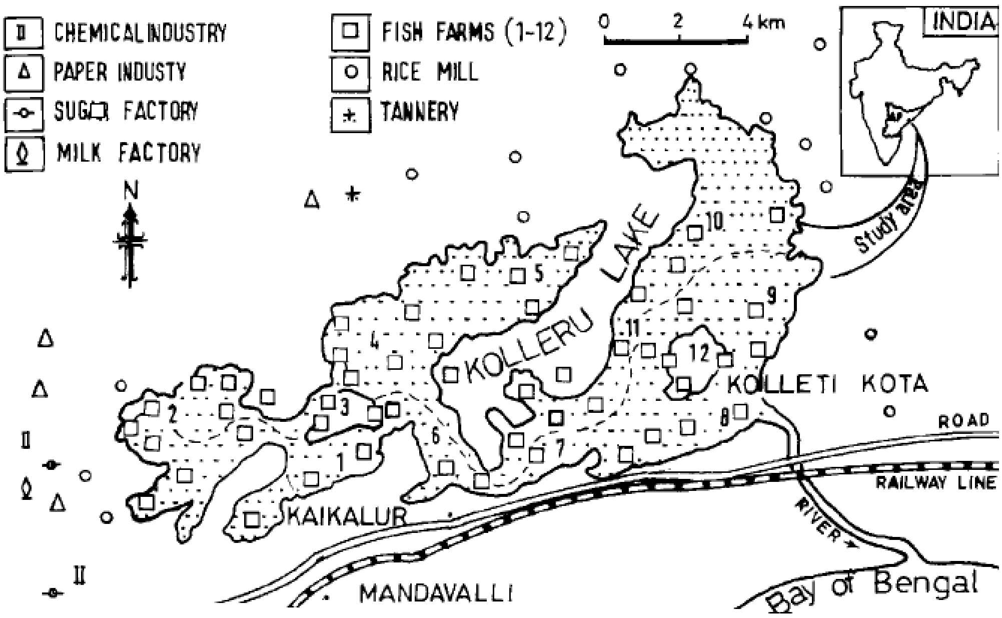

Figure 31: Locations of fish farms in the Kolleru Lake region. Adapted from [60]

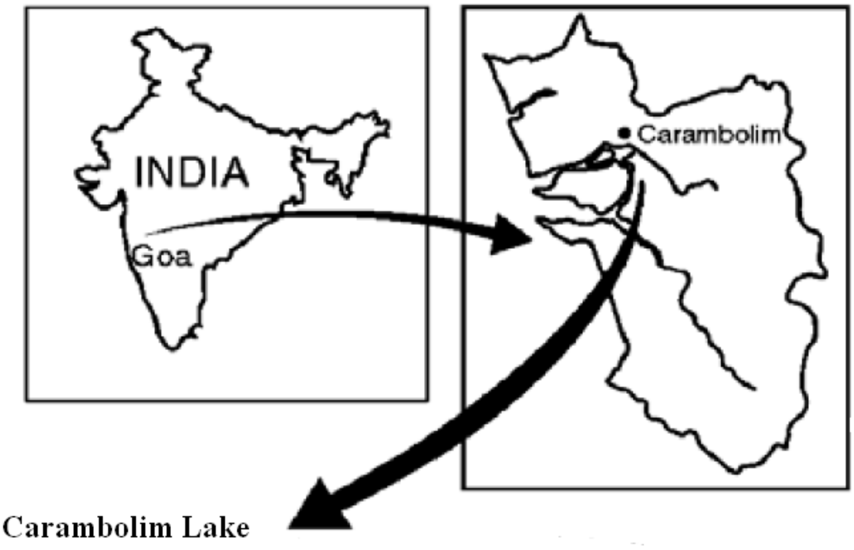

Figure 32: Location map of Carambolim Lake in India. Adapted from [61]

4.6 Characteristics and present situation of water resources in Korea

4.6.1 Rivers

Papers [65], [66], [69] and [72] analyzed water quality issues in Korea based on the following problems: DO, BOD, N, P and COD_{Cr}.

The Nakdong River (Figure 33), which is one of the four major river systems in Korea, serves as an important water resource for the South Eastern area. Currently, about 7 million people reside within the basin and more than 13 million people use drinking water from the river. During the last decades, the combination of rapid population growth coupled with industrial and urban development resulted in a serious deterioration of the downstream water quality. Major pollution sources include domestic sewage, industrial wastewater, livestock discharge, and urban and agricultural runoff [64].

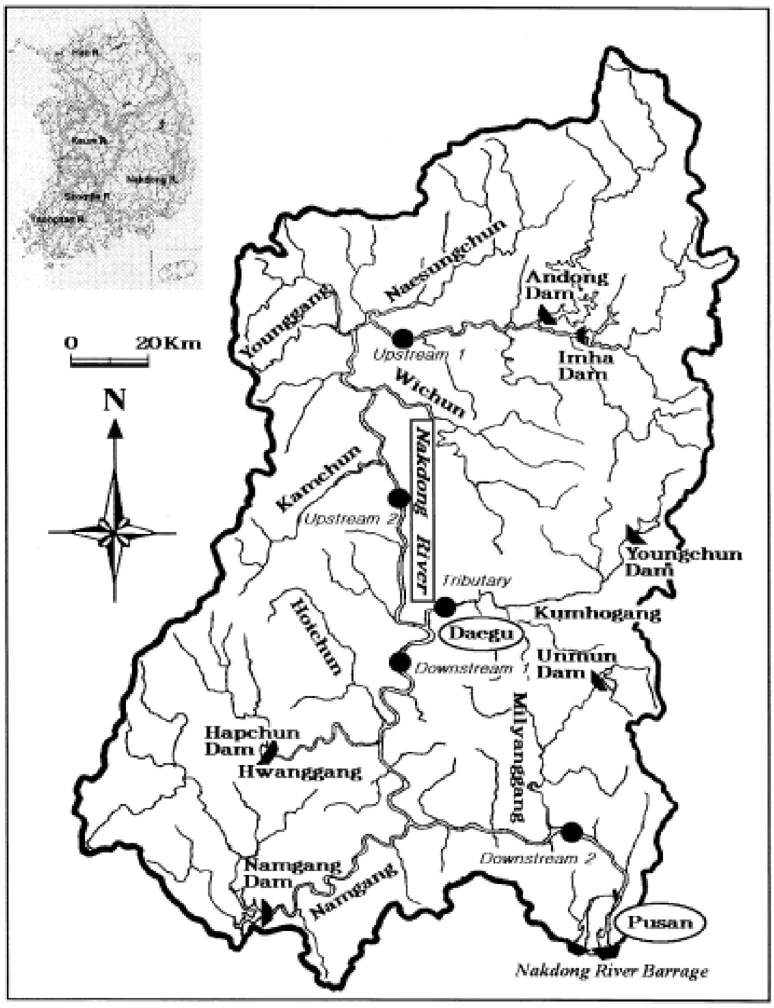

Figure 33: Rihand Reservoir and surrounding area [65]

The Kyongan stream is the first tributary of the Han River, which is 49.5 km long and has 558.6 km^2 of watershed area. During the rainy season, pollution discharge is mainly influenced by the flow rate. At the initial stage of rainfall, peak concentration of organic matter comes out before peak flow rate in every rainfall events. The unit load in response to rainfall events in the Kyongan stream basin were obtained according to the water analysis (Table 7). Hence, the authors of the study concludes that it is important to manage the first flush in order to control pollutants from NPS [71].

Table 7: The unit load in response to railfall events the Kyongan stream basin (kg/ha/year) [71]

Watershed	**BOD**	**CODcr**	**SS**	**TOC**	**T-N**	**T-P**
Urban area	19.1	200.0	2923.5	54.7	37.1	17.7
Agriculture area	7.6	26.8	1066.5	14.8	7.7	4.8
Mountainous area	2.2	43.6	798.5	40.0	26.4	10.5

4.6.2 Lakes

Lake Shihwa is an artificial saltwater lake located on the West coast of South Korea (Figure 34), with the lake providing a habitat for aquatic animals and birds. There are large industrial complexes (total industrial area = 31 km^2) in this region. Approximately 13000 companies, largely mechanical, electrical/electronic, petrochemical, steel and textile companies are currently operated in the complex areas. The cities of Shiheung and Ansan (total population exceeds 1 million inhabitants) are located on Lake Shihwa. The dike was finished in 1994 after seven years construction and separates Shihwa Lake from the Yellow Sea. Since 1980s, two industrial complexes, Shihwa and Banweol, have been established along the Shihwa Lake. Shihwa Lake was originally designed to provide freshwater sources for various factories along the lake with the gradual replacement of seawater into freshwater. The restriction of water exchange with the outside sea after the dike construction and the insufficiency of creek water flowing into the lake, however, resulted in serious deterioration of the water quality in the lake and the original plan of freshwater usage was finally abandoned [67, 80].

Rapid growth of the population and industrial development has led to deterioration in water quality and biodiversity in this region. The overall concentrations of PBDEs in water from Lake Shihwa and surrounding creeks varied widely. Total concentrations of 23 PBDE congeners in water ranged from 0.16 to 11.0 ng/l (1 ng = 1×10^{-6} mg). The concentrations of PBDE 209 in water were 1-2 orders of magnitude higher than the total concentrations of other PBDE congeners. The highest concentrations of PBDEs in water were found in creeks near industrial complexes. The PBDE concentrations gradually decreased with increasing distance from the creeks to the inshore and then offshore regions of the lake. BDE 209 was a major congener, accounting for 80% of the total PBDEs in water, consistent with a high consumption of deca-BDE for the brominated flame retardant market in Korea [66].

Other authors studied the contamination of nonylphenolic compounds in the Shihwa Lake [67, 70]. Freshwater in Lake Shihwa is contaminated by NPs and COP. Total NP (the sum of nonylphenol, and nonylphenol mono- and di-ethoxylates) were 0.32-875 μg/l in creeks and 0.61-87.0 μg/l in WWTP effluents. Concentrations of COP were 0.09-19.0 μg/l in creeks, and 0.11-44.0 μg/l in WWTP effluents.

WWTP discharge to Lake Shihwa was considered a major contributor of industrial wastewater pollution.

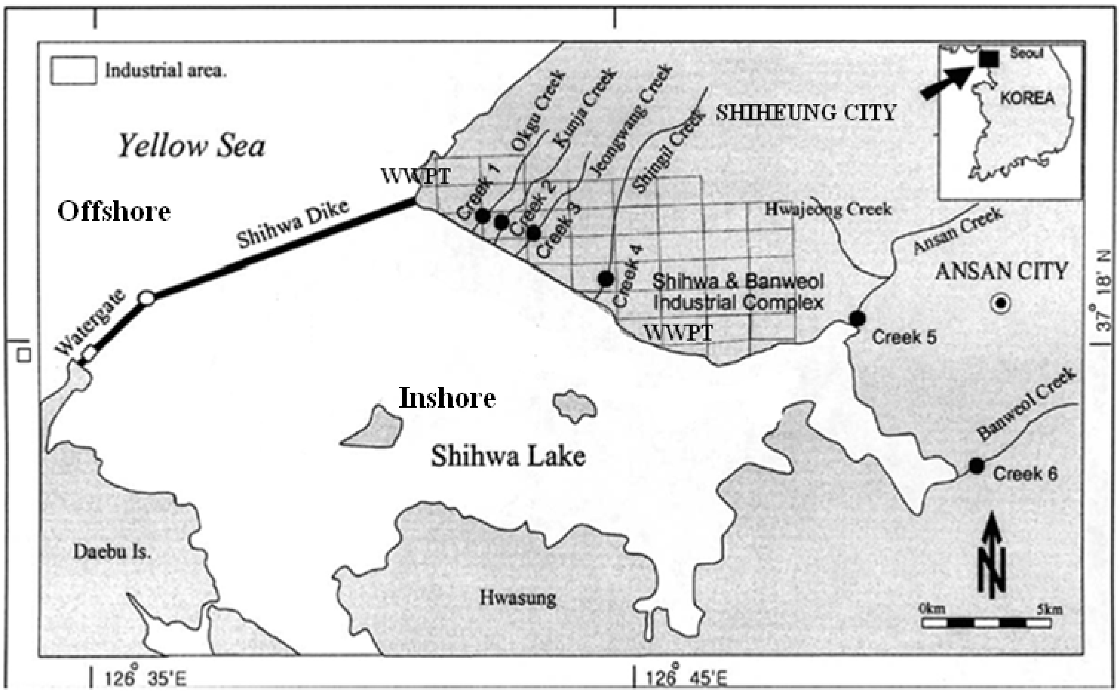

Figure 34: Location map of Lake Shihwa in Korea. Adapted from [67, 80]

4.6.3 Reservoirs

The Yeongsan Reservoir (Figure 35) is an estuarine reservoir which provides surrounding areas with public goods, such as water supply for agricultural and industrial areas and flood control. Water quality in the Yeongsan Reservoir was deteriorated caused by the continuous and numerous point and NPS of pollution discharging into the Reservoir, causing eutrophication.

Table 8 summarizes the basic statistics of the station average 5-year water quality parameters from the YS Reservoir; the water quality of YS Reservoir could be characterized by high nutrients concentration (i.e., TN and TP) and TC concentration [69].

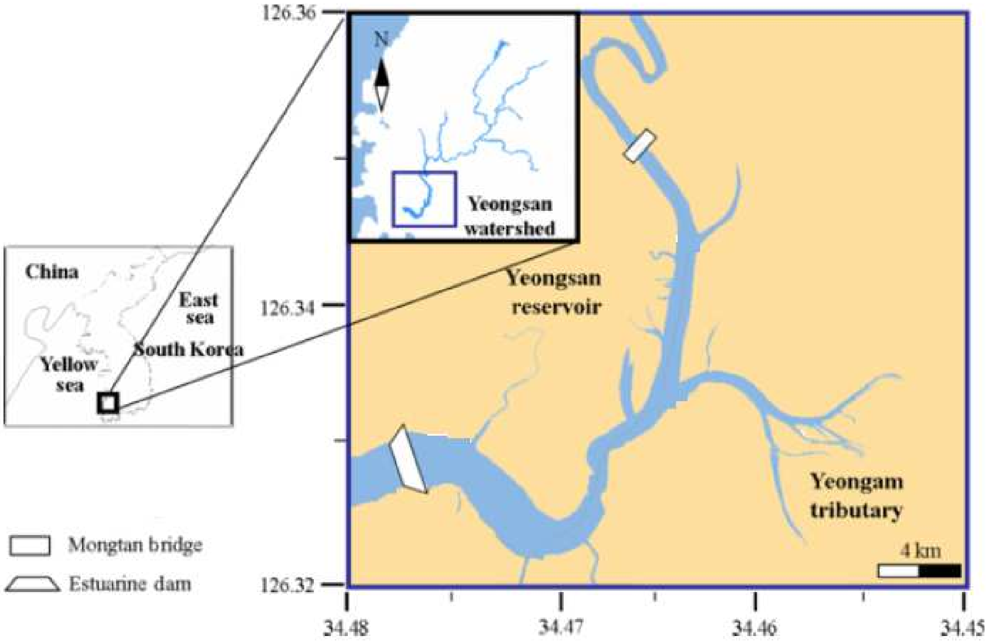

Figure 35: Location map of Yeongsan Reservoir. Adapted from [68]

Table 8: Basic statistics for the YS Reservoir. Adapted from [69]

Parameter	Unit	Average	Maximum	Minimum
Water temperature	°C	16.4	29.0	3.0
pH	mg/L	7.7	9.1	7.1
DO	mg/L	8.9	17.4	3.8
BOD	mg/L	2.2	6.6	0.5
COD	mg/L	5.3	8.5	3.2
SS	mg/L	14.4	65.8	4.1
TC	mpn/100 ml	2,717	79,830	3.7
TN	mg/L	4.8	8.8	2.0
TP	mg/L	0.22	0.60	0.10
SD	M	0.95	2.80	0.30
Chlorophyll-a	mg/m^3	13.1	61.2	0.1
EC	µmhos/cm	1,105	3,325	131
NO_3^- -N	mg/L	2.64	5.20	0.10
NH_4^+–N	mg/L	0.42	2.70	0.00
FIB	mpn/100 ml	232	4,501	1.0
PO_4^{3-} -P	mg/L	0.12	0.20	0.0
DTN	mg/L	3.9	8.2	1.7
DTP	mg/L	0.12	0.2	0.0

4.7 Information concerning water resources in other Asian countries

4.7.1 Malaysia

The Selangor River basin (Figure 36) covers an area of 2,200 km^2 in the most industrialized state in Malaysia. While the Northern part of the basin is covered by forest, the Eastern and Central part are developed for agriculture uses, mainly palm oil and rubber plantations. Water resource issues in Malaysia have grown in magnitude and complexity in recent years. This can be attributed to the fact that Malaysia has undergone extensive land conversion from agricultural to urban-industrial-commercial use. Based on the Department of Environment monitoring data, the main pollution sources of Malaysian rivers are from sewage treatment plants (46.7 %), manufacturing industries (47.2 %), livestock farming (3.7 %) and agro-based industries (2.4 %) [72].

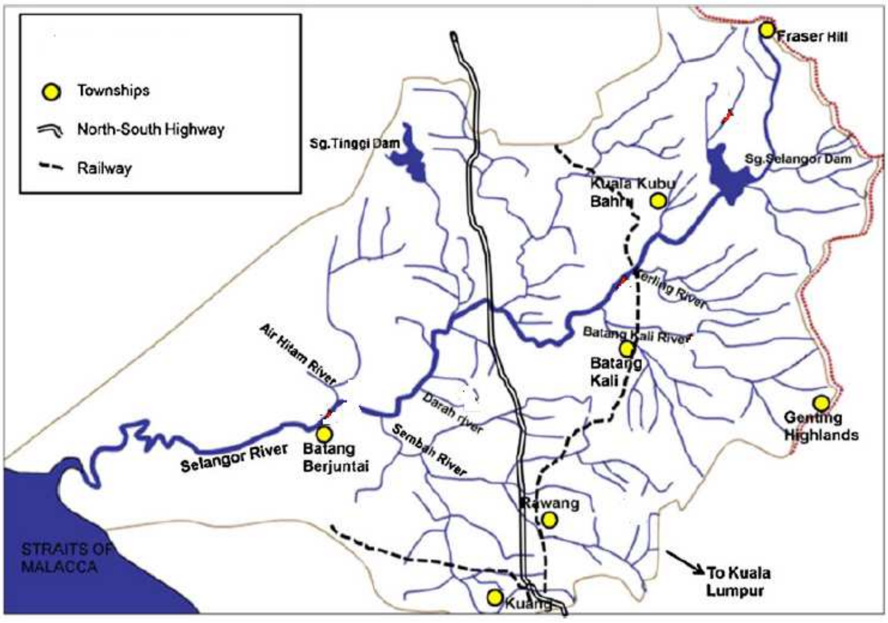

Figure 36: Map of Selangor River basin

Due to its persistent nature and heavy discharge in the past, OCPs (Σ_{15}OCPs ranging from 0.6-25.2 ng/L) such as lindane, DDTs and HCB are still detected in water at low concentrations while others like heptachlor, and aldrin were not detected. Meanwhile, the plasticisers (BPA concentration ranged from <1.2 to 120.0 ng/L) were detected at higher concentrations and more frequently; usually at the more urbanized sites located downstream and during the dry season. DEHP concentration was the highest in the river. Although the detected levels are comparable to slightly impacted water elsewhere, total PAEs at downstream river which exceeded 1 µg/l is a cause for concern for the aquatic life [71].

The author also analyzed the concentrations of PAEs and BPA during the rainy and dry seasons (Table 9). Lower concentrations were expected during the rainy season due to the dilution factor. Concentrations of DEP, BPA and DEHP were higher during the dry season. However, concentrations of DMP, DBP, BBP and DOP were almost unchanged. This can be partly attributed to the release of freshwater from the Sungai Selangor dam during dry season to meet the demands from the treatment plants located further downstream.

Table 9: Mean concentration of the studied compounds detected during rainy and dry season. Adapted from [72]

Mean concentration	**DMP**	**DEP**	**DBP**	**BPA**	**BBP**	**DEHP**	**DOP**
Rainy Season	7.1	28.6	108.9	15.3	6.9	130.9	2.3
Dry Season	9.2	36.4	109.9	22.1	9.0	210.8	4.5

4.7.2 Philippines

The Laguna Lake (Figure 37) is the largest inland water resource in the Philippines and an important source of fisheries in the area. The Pagsanjan-Lumban catchment is the main freshwater input of the lake but contaminants resulting from agricultural activities within the catchment may impact fisheries.

Figure 37: Location of Laguna Lake (red sit)

Of the pesticides used in the agricultural activities in the Pagsanjan-Lumban catchment the pyrethroids were found to be the most toxic to freshwater shrimp. The maximum measured concentration of profenofos (15.4 µg/l) and pyrethroids (3-6 µg/l) in the field samples collected in waterways in the Pagsanjan-Lumban catchment were above the 48 h LC_{50} values for shrimp. These compounds posed a high hazard (HQ > 1) to freshwater shrimp and Tilapia in the Pagsanjan-Lumban catchment [75].

4.7.3 Pakistan

Rawal Lake is situated in Islamabad across Korang River at a distance of about 10 km from Rawalpindi (Figure 38). The surface area of the lake is about 8.8 km^2. Untreated effluents from communal, agricultural, and poultry sectors are seriously damaging the surface water quality in Rawal Lake. Unhygienic condition of Rawal Lake is seriously increasing the negative impacts on surrounding environment and cost of treatment of lake water to get water for drinking purpose.

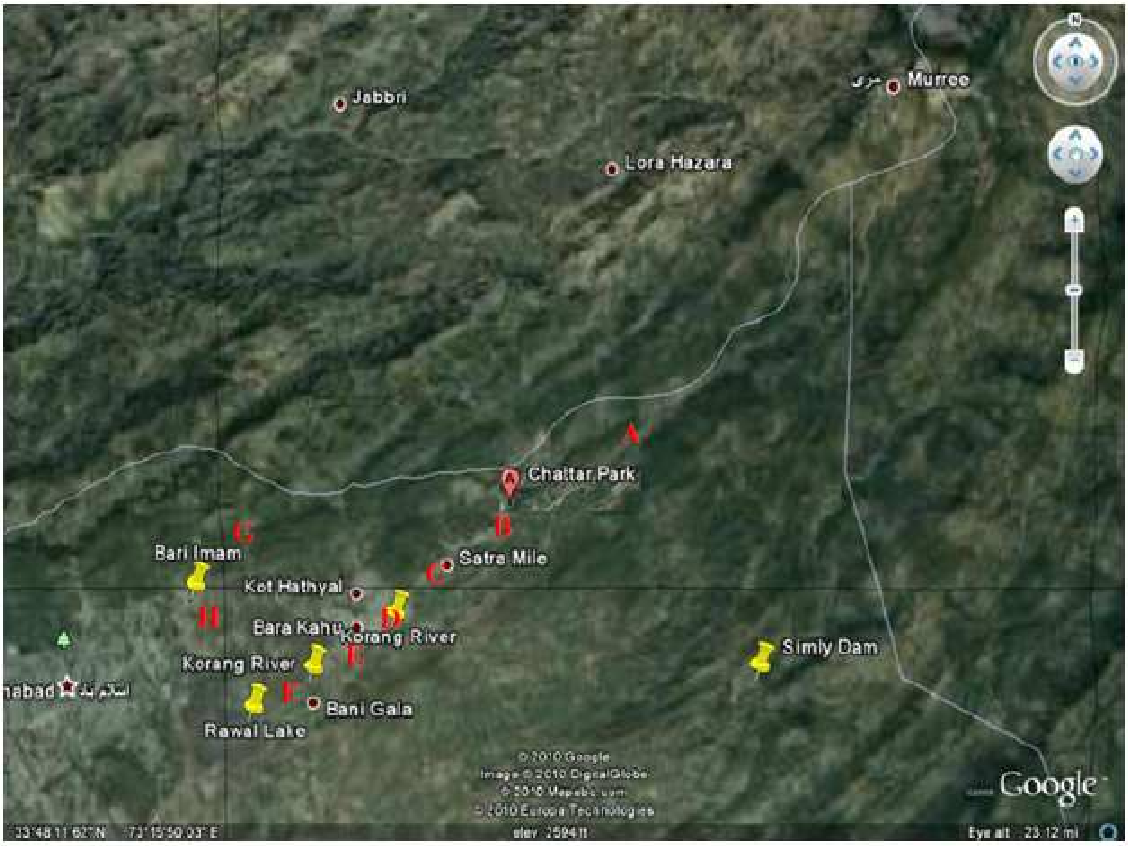

Figure 38: Map of Rawal Lake [76]

Spatial analysis (Figure 39, 40, 41) of the concentration, of different water quality parameters (Ca, chlorides, TDS) proves that contamination increases significantly at each step, as the river water approaches towards the lake. Every picnic point, every village and newly developed residential colonies are adding towards contamination of River Korang and its tributaries [76].

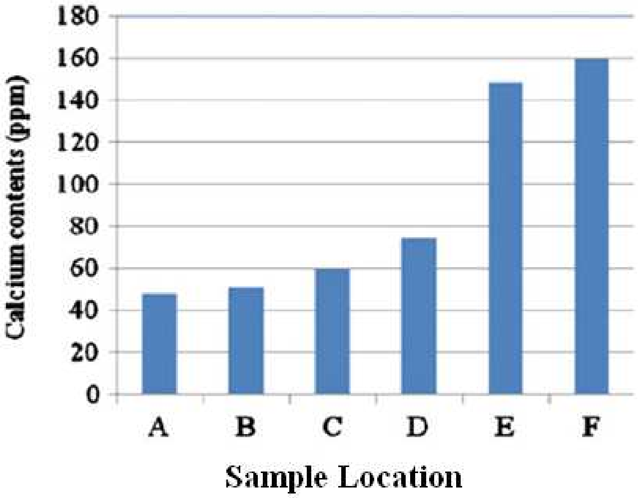

Figure 39: Spatial variation of Ca contents [76]

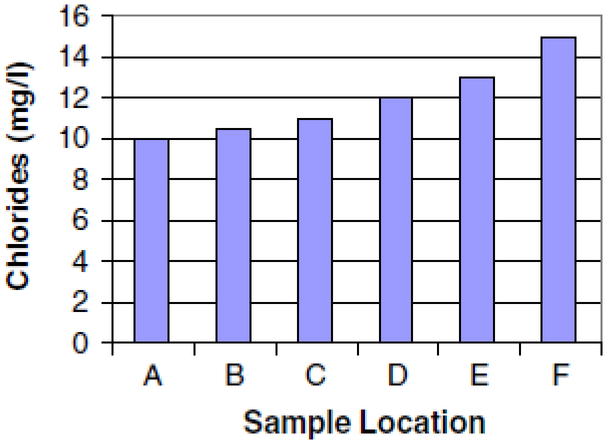

Figure 40: Spatial variation of chlorides [76]

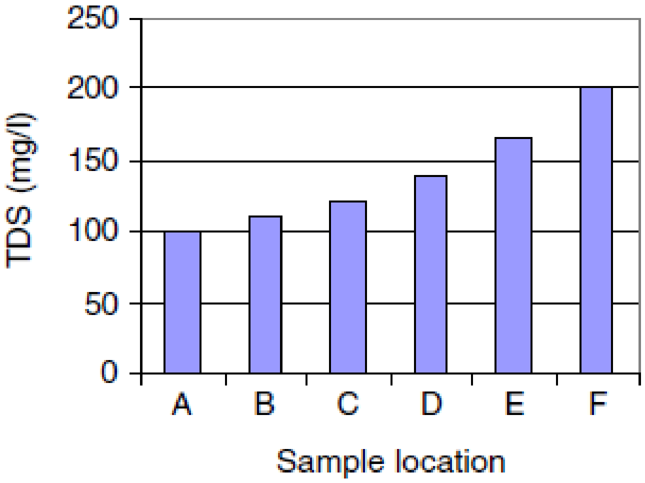

Figure 41: Spatial variation of TDS [76]

4.7.4 Thailand

Chao Phraya River basin is the major river system in Central Thailand (Figure 42), which supplies water to a major metropolitan region. It covers 160,000 km^2, representing 30 percent of the country's total area and it is the source water for 23 million people. PFOA was the most dominant PFC, while PFPA and PFOS were also highly detected in most of the river. The average loadings of PFPA, PFOA and PFOS in Chao Phraya River were 94.3, 284.6 and 93.4 g/day, respectively [77].

4.7.5 Laos

Houay Xon stream is a part of the Mekong basin in Northern Laos (Figure 43). The Mekong River lies in Southeast Asia and its 800,000 km^2 catchment encompasses parts of Southern China, Myanmar, Thailand, Laos, Cambodia and Vietnam. A high degree of bacteriological contamination occurs in stream water as they pass through villages and peri-urban areas. Clearly the human footprint increased as one moves downstream. The most common sources of pollution are from urban household wastewater which may potentially contain pathogens and local groundwater supply when low dissolved oxygen conditions prevail, which may favor high metal accumulations in aquatic plants [78].

The authors of paper [78] concluded that in the near future, it will lead to an increased demand for sanitation infrastructures and freshwater resources, notably for irrigated peri-urban market gardens. Extending basic drinking water and sanitation services to peri-urban areas and neighbouring villages in order to reach the poorest people is of importance to prevent outbreaks of cholera and other water related diseases.

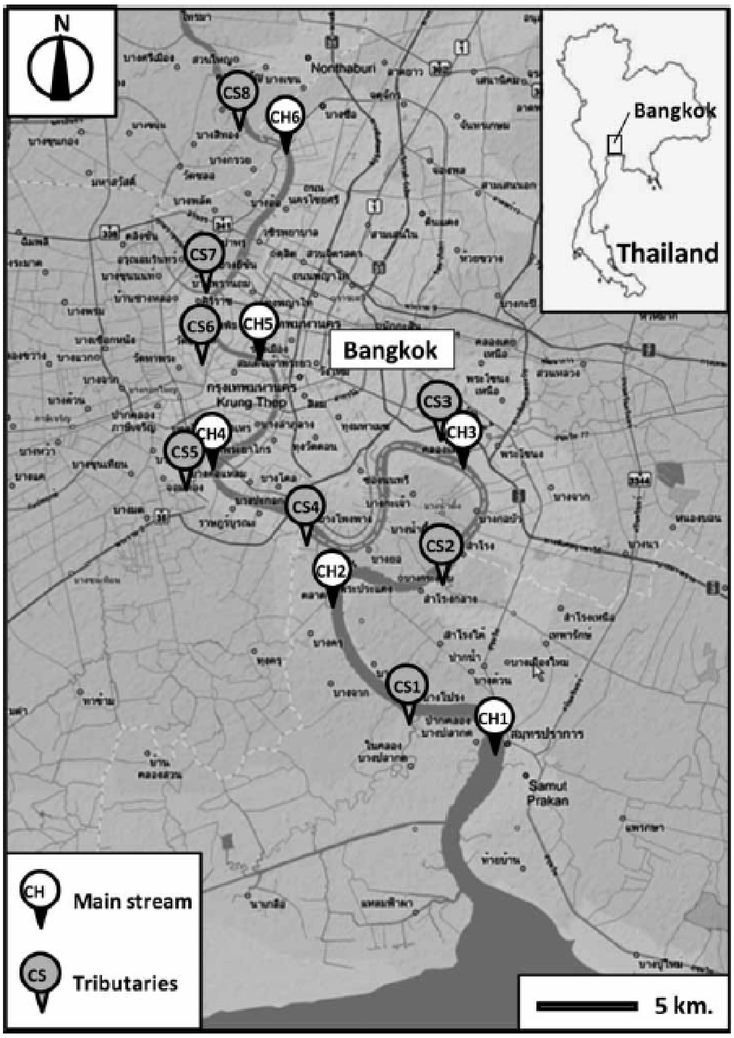

Figure 42: Location of Chao Phraya River. Adapted from [77]

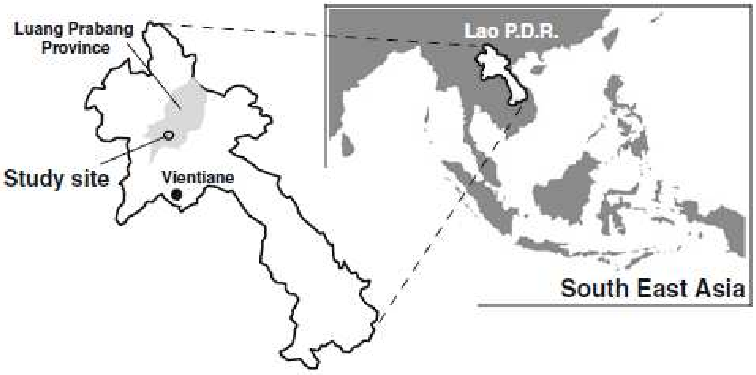

Figure 43: Location of study site (Mekong River). Adapted from [78]

4.7.6 Singapore

The Marina Catchment (Figure 44) covers approximately one-sixth (10,000 ha) of Singapore’s land area and includes a major section of the city centre. Marina Reservoir is in the early stages of conversion to a freshwater reservoir. The depth profiles showed that the reservoir is vertically stratified with surface layers containing up to 86% freshwater with large variance and bottom layers sustainably 98% seawater. Surface layers contain higher PFC concentrations than the bottom layers. Approximately 70% of freshwater input is originated from runoff, 25% from dry weather flow and 5% from rain, respectively [80].

Marina Catchment

Figure 44: Location of Marina watershed and Reservoir

The composition of PFCs in runoff and reservoir water was similar to storm runoff. The PFC content in the Marina Reservoir sediments was higher compared with those measured elsewhere. Sedimentation was the major sink for PFCs. The estimated annual PFC input into the reservoir was approximately 35±12 kg y^{-1} [80].

4.7.7 Mongolia

The Kharaa River basin is located in Northern Mongolia (Figure 45) and the river is 362 km long. Total emissions from point and diffuse sources of pollution for the year 2005 amounted to 500 t/year of TN and 122 t/yr of TP. The portion of different emission pathways shows that urban areas and especially the point sources (WWTP) are the most relevant contribution to the total emissions [81].

Figure 45: The Kharaa River basin (dark tint) as part of the Selenge catchment (hatched) which drains an important area of Mongolia [81]

4.7.8 Uzbekistan

The Aral Sea drainage basin is an endorheic basin (Figure 46) of 1,874,000 km^2, which comprises two principal rivers that discharge into the Aral Sea; the 2400 km long Amu Darya River and the 2500 km long Syr Darya River. The Mejdurechye reservoir, having an area of about 180 km^2 and a maximum depth of 4 m, is one of the largest water bodies in the delta and has become a new terminal water body of the delta [82].

As Figure 46 shows, the blue part is Aral Sea. Figure 47 illustrates the water losses in the Aral Sea during 1960 to 2002. The surface area of Aral Sea once measured 66,100 km^2, but now it is just a quarter of the size in 50 years ago and has broken into several parts, the North Aral Sea and the South Aral Sea [87].

Amu Darya river discharge constitutes a major part (about 70%) of the renewable water resources within the Aral Sea drainage basin. Through extensive use of fertilizers, pesticides and herbicides, toxic chemicals including DDT, γ-HCH, As and Cu have been spread over the agricultural fields. Surplus irrigation water evaporates or returns to the rivers, which results in downstream accumulation of agrochemicals and salt in the rivers. Due to the well developed mining industry, a main pollution source in Aral Sea drainage basin is acid mine drainage which generally contains high metal concentrations. As a consequence, the concentrations of Cu, Pb, Ni, Mn and Cr were detected at levels exceeding the WHO drinking water guideline values (Table 10) in the Amu Darya delta [82].

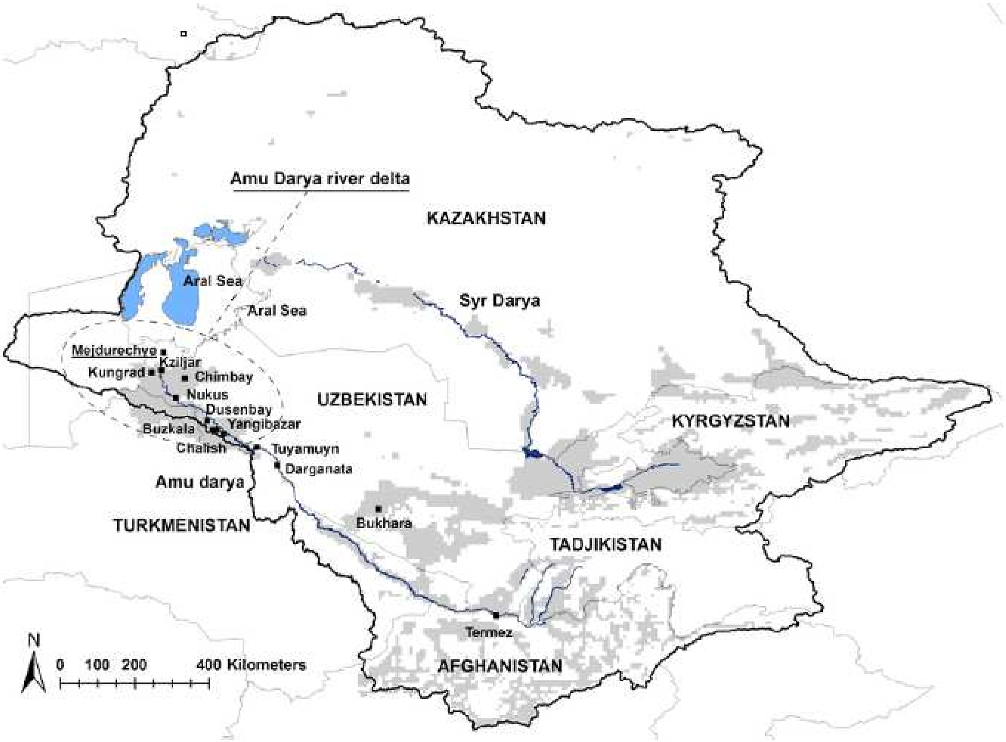

Figure 46: The Aral Sea drainage basin (black solid line) with the Amu Darya river delta (dotted line) south of the sea, in which Mejdurechye Reservoir is located [82]

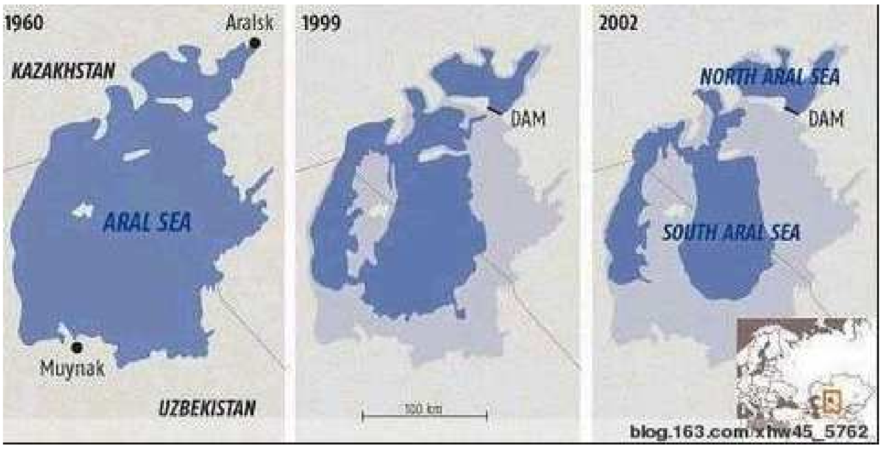

Figure 47: The shrinking of the Aral Sea from 1960 to 2002 [86]

Table 10: Guideline values for drinking water quality from WHO (2006). Adapted from [82]

	Cr	**Cu**	**Mn**	**Ni**	**Pb**
WHO (µg//l)	50	2000	4000	70	10

4.7.9 South Asia (India and Bangladesh)

Two of the papers found concerned water quality issues from South Asia. Although India was already considered in another chapter, it is included here information from sources [83, 84].

The surface water system in South Asia includes a dozen major rivers that include the Indus (India and Pakistan), the Ganges (India, Nepal and Bangladesh), the Brahmaputra (Tibet, India and Bangladesh) in the North, while the Central region is drained by the Narmada, the Tapti, the Mahanadi and the Sabarmati. The Southern region presents the following rivers: the Godavari, the Krishna, the Cauvery and the Periyar (Figure 48).

The water quality for some of the large rivers at their respective river mouth is summarised in Table 11. All the rivers, in general, show high carbonate alkalinity independent of the local lithology; rock weathering involving atmospheric CO_2 and minerals in different lithology uniformly releases Ca^{++}, Mg^{++} and HCO_3^- to the river water. South Asia has water contamination from all types of human activities either directly or indirectly: persistent organic chemicals (POP) such as DDT and pesticides, toxic metals such as Hg and As, general contaminants such as P and N in sub-surface water, excess coliform and other bacterial population beyond MPN (Most Probable Number as per EPA definition). The population is thus vulnerable to all forms of water pollution problems [83].

Paper [84] presents the current status and trend in surface water pollution and to identify the major sources and causes of pollution in the urban territories in the context of three South Asian urban areas, namely; Dhaka in Bangladesh (Figure 49), Delhi in India (Figure 50), and Kathmandu valley in Nepal (Figure 51).

The Bagmati River in Kathmandu valley, the Yamuna at Delhi, and surface water resources around Dhaka are highly polluted and unfit for the designated water uses. High organic and pathogenic levels in all urban surface waters have resulted from huge discharge of municipal wastewater (sewage and industrial wastewater) and urban drainage into the rivers. Average annual BOD and total coliform in the rivers of Dhaka, the Bagmati in Kathmandu, and the Yamuna downstream of Delhi are in the range of 20-25 mg/l and 104-105 MPN/100 ml, respectively. Seasonal variation in water quality of the Bagmati and Yamuna reveals a more critical situation during the dry season (December to May). In those months, BOD rises to 90 and 45 mg/liter in the Bagmati and Yamuna, respectively, and DO drops to almost zero. Average per capita pollution discharge to the rivers is estimated to 31, 20, and 25 g BOD/person/day in the Bagmati, Yamuna, and Dhaka rivers, respectively. In the Buriganga and Bagmati rivers, DO has decreased annually at a rate of nearly 0.3 mg/l/yr. In all these cities, municipal sewage contributes for nearly 85% of all pollution in the rivers. To date, Nepal still lacks ambient water quality standards or other comprehensive effluent standards. However, in India and Bangladesh, primarily an effective implementation of established standards is lacking. As enforceable regulatory or other measures have not yet been sufficiently developed, municipal sewage is a continuing problem in reducing the total pollution load of the rivers [84].

Figure 48: Location of major rivers in South Asia [83]

Table 11: Average chemical composition (ppm) of South Asian Rivers [83]

Country	River	HCO_3	Cl	SO_4	SiO_2	Ca	Mg	Na	K	TDS
India	Kerala Rivers	12	7	4	9	3	2	5	1	39
	Cauvery	135	20	13	23	21	9	43	4	272
	Gomti	274	9	15	15	30	19	27	5	394
	Krishna	178	38	49	24	29	8	30	2	360
	Godavari	105	17	8	10	22	5	12	3	181
	Mahanadi	122	23	3	17	24	13	14	8	224
	Narmada	225	20	5	9	14	20	27	2	322
	Tapti	150	65	1	16	19	22	48	3	322
	Indus	64	5	23	5	54	12	10	0.3	173
	Indian Rivers	74	15	13	7	30	7	12	3	159
	Ganges	128	10	11	18	25	8	11	3	241
Bangladesh	Brahmaputra	56	11	4	7	14	5	7	3	107

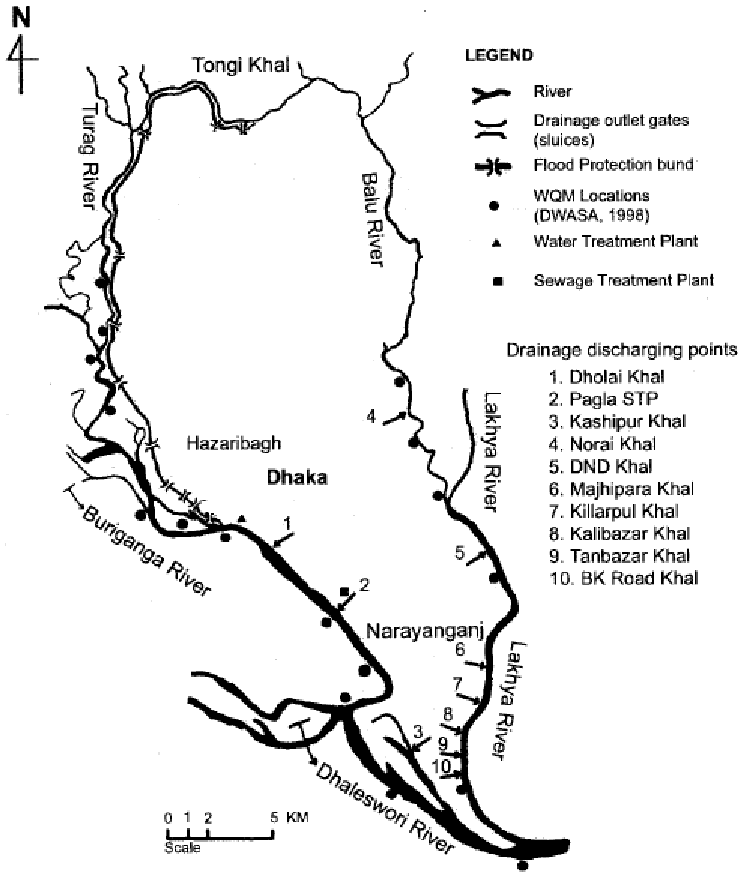

Figure 49: River and drainage system around greater Dhaka. Adapted from [84]

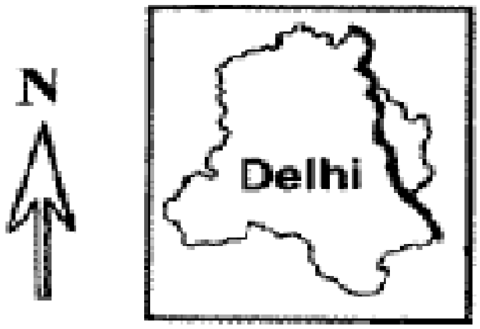

Figure 50: Yamuna River in Delhi urban area (Black thick line). Adapted from [84]

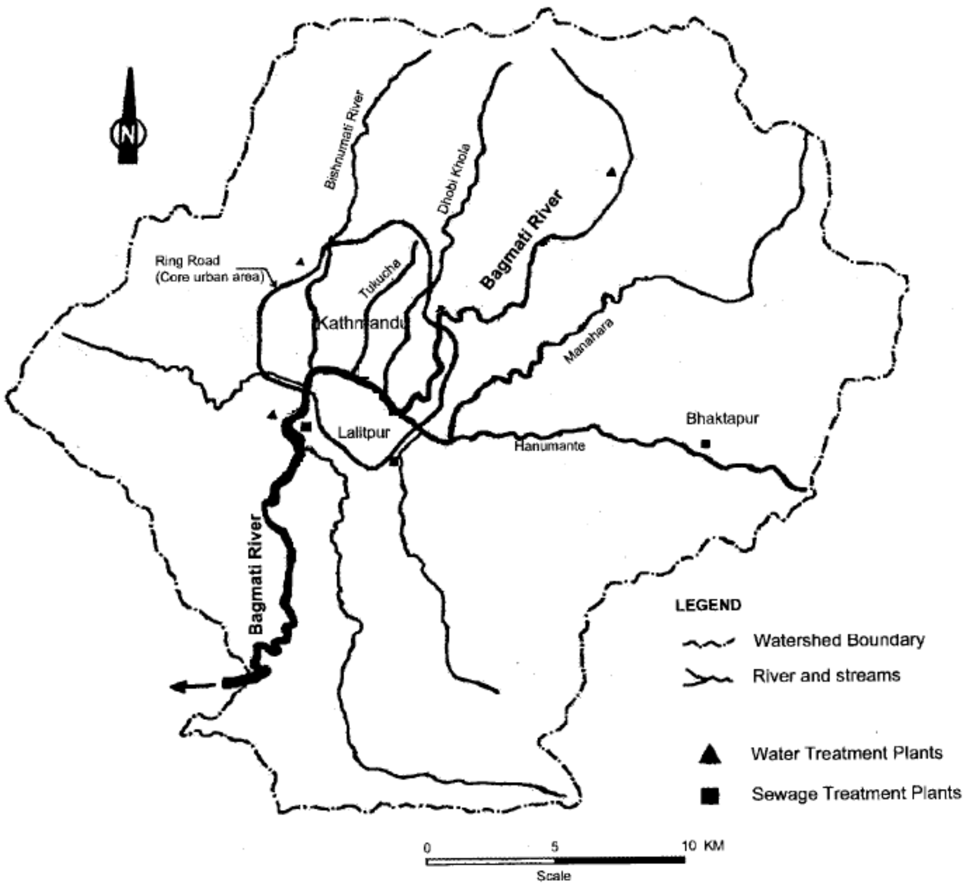

Figure 51: River and drainage system in Kathmandu valley. Adapted from [84]

5. Analysis of methodologies used for assessment of rivers, lakes and reservoirs water quality

5.1 Most important water quality problems in Asia countries

As it is well-known and was mentioned in the first chapter of this report, activities from agriculture, industrialization, and urbanization are a cause of increase in the degree of pollution of rivers, lakes and reservoirs.

As Table 12 illustrates, the main sources of point pollution in the Asian countries analyzed in this study are industrial effluents and discharge of domestic sewage, which contain organic pollutants, chemicals and heavy metals.

NPS pollution includes agriculture, street runoff, mine sites, etc. According to the gathered information (Table 13), agricultural is the most relevant source of non-point pollution present in Asian countries. Fertilizer, pesticide and other pollutants from agricultural land can reach the water bodies transported by surface runoff. The excessive nutrient loading from agricultural watersheds is considered to be the principal reason of eutrophication of water masses. In China and Japan, this problem is especially severe, probably due to the fact that they have a high fertilizer application rate in agriculture in order to support their large population.

Table 12: Number of studies from the 52 literature sample cases that concern Point and NPS pollution

Pollution sources		**China**	**Japan**	**India**	**Korea**	**Other countries**	**Total**
Point	Industrial	$7^{\#}$	$2^{\#}$	$7^{\#}$	$6^{\#}$	$5^{\#}$	**$27^{\#}$**
	Domestic	$5^{\#}$	$1^{\#}$	$7^{\#}$	$3^{\#}$	$5^{\#}$	**$21^{\#}$**
NPS	Agricultural	$8^{\#}$	$6^{\#}$	$4^{\#}$	$5^{\#}$	$5^{\#}$	**$28^{\#}$**
	Mining activities	$1^{\#}$	$1^{\#}$	$1^{\#}$	$0^{\#}$	$3^{\#}$	**$6^{\#}$**
Other sources		$2^{\#}$	$1^{\#}$	$4^{\#}$	$0^{\#}$	`$1^{\#}$	**$8^{\#}$**

The other sources include geological factors [44], municipal wastewater [22, 54, 61, and 63], atmospheric transport and pollutant deposition [37], tourism pollution [62] among others.

5.2 Different methodologies used for evaluation of water quality

5.2.1 Overview of the different methodologies

Evaluation of water quality is crucial to safeguard public health and the environment. Based on the relevant literature information collected, three methods were found to be the most common in the assessment of water quality. i) field monitoring, including large database for a long period of time [32, 35, 42, 44, 47, 54, 59, 73, 84] and more restricted data [33, 37, 38, 39, 40, 41, 43, 48, 49, 50, 51, 52, 53, 54, 55, 58, 60, 62, 63, 67, 69, 70, 71, 72, 74, 77, 80, 82]; ii) statistic methods, including PCA [31, 33, 41, 52, 69], CA [31, 54, 58], FA [20, 31, 54], etc. and iii) modeling, including SWAT [14, 24, 45], QUAL2E [64, 68], Mass Balance Model [42, 57], etc.

The most used methodology was unquestionably the field monitoring, with 48 studies, representing 84% of the sample used in this analysis. Both statistic methods and modeling were represented with 28 studies, which accounted for 49% of the total sample of studies.

5.2.2 Field monitoring

From the literature sample, 49 studies (86%) were based in field monitoring. Therefore it seems that monitoring data, concerning both hydrological variables and water quality parameters is the most used method in assessment of water quality. Papers [45, 60] showed that sometimes the authors use data from historical databases from a certain relevant Agency, Department, Office or System; however the most common is to gather data from continuous monitoring in different spatial-temporal scenario, following a designed monitoring program.

There is a wide range of sampling methods which depend on the type of environment, the material and the subsequent analysis of the sample. Analyzing the 52 papers collected, it is possible to classify three types of sampling methods as follows:

1) Grab samples. A grab sample consists of a single sample taken at a specific time and then filling a clean container (e.g. glass/PET bottles, stainless steel bucket, etc.) (see examples in Figure 52, 53). This is the most common type of sample. A grab sample has certain limitations. In essence, a grab sample takes a snapshot of the characteristics of the water at a specific point and time, so it may not be completely representative of the entire flow. Grab samples are most appropriate to small water masses with low flows and limited staff that cannot perform continual sampling. Many papers in this study used grab samples (for example papers [33, 38, 46, 49, 71, 73, and 81]).

2) Semi-continuous monitoring. Paper [70] describes a specialized sampling equipment that is programmed to take samples at fixed time intervals (see example in Figure 54). Semi-continuous monitoring requires some protection for the equipment placed close to the environment being monitored. Usually the results can be read in real time.

Figure 52: Collecting a grab sample on a stream [89]

Figure 53: Collecting a grab sample on a river by boat [90]

Figure 54: An automated sampling station and data logger (to record temperature, specific conductance, and DO levels) [89]

3) Passive monitoring with automatic equipment or other devices (see example in Figure 55). There is just one paper [39] focused on this method. Passive samplers can provide a representative picture of levels of pollutants over a period of time from days to months by measuring the average concentrations to which they have been exposed. Passive sampling devices are now becoming increasingly used to monitor pollutants in rivers, coastal waters and ground water where contamination results from sources such as domestic and industrial discharges, and the use of agrochemicals. As Figure 55 shows, a small boat deploying an Acoustic Doppler Current Profiler. This device measures river flow and scans the river bed to give information about how much water is flowing from and into. The use of passive samplers can greatly reduces the cost and the need of infrastructures on the sampling location, thus they can be employed in many locations, allowing a better coverage and more data being collected.

Field monitoring may allow the researchers to obtain data though remote sensing. In papers [74, 79], water quality multi-parametric probes were placed “in situ” with network connection to computer system at the office. Remote sensing makes it possible to collect data on dangerous or inaccessible areas

Figure 55: Water monitoring near a river[91].

5.2.3 Statistical techniques

Since no individual parameter can express the water quality (WQ) sufficiently, the WQ is normally assessed by measuring a broad range of parameters (e.g., temperature; pH; electric conductivity (EC); turbidity; and the concentrations of a variety of pollutants, including pathogens, nutrients, organics, and metals). In addition, WQ monitoring over a long time for many sampling sites produces a very large and complex data set, it is difficult to analyze and interpret all this data to extract comprehensive information for WQ. In the recent past, different multivariate statistical approaches have been applied for assessment of large WQ data sets, such as cluster analysis (CA), discriminant analysis (DA), and principal component analysis (PCA). These statistical methods help the interpretation of complicated data matrices, a better understanding of the temporal and spatial variances of water quality, allowing the identification of possible factors that influence the water systems [31, 74]. The authors of paper [31] elaborate on three relevant statistical techniques:

1) Cluster analysis

CA is an unsupervised pattern recognition method that divides a large amount of cases into smaller groups or clusters based on the characteristics they possess. The resulting clusters of objects should exhibit high internal (within cluster) homogeneity and high external (between clusters) heterogeneity. Hierarchical CA is the most common approach, which starts with each case in a separate cluster and joins the clusters together step by step until only one cluster remains and is typically illustrated by a tree diagram. The tree diagram provides a visual summary of the clustering process, presenting a picture of the groups and their proximity, with a dramatic reduction in dimensionality of original data. The Euclidean distance usually gives the similarity between two samples and a distance can be represented by the difference between analytical values from samples [31].

As Figures 57 illustrates, the use of CA to analyze the temporal similarities and grouping applied in paper [31]. An initial exploratory approach involved the use of hierarchical CA on standardized log-transformed data sets sorted by the 12 months. CA generated a tree diagram (Figure 56), grouping two clusters. Period 1 included January, February, March, and April. Period 2 included the remaining months (May, June, July, August, September, October, November, and December). The result is different from the empirical classification, which is accustomed to dividing into four seasons (spring, summer, autumn, and winter) or into dry/wet seasons, indicating that the temporal grouping pattern of water quality was inconsistent with the traditional classifications.

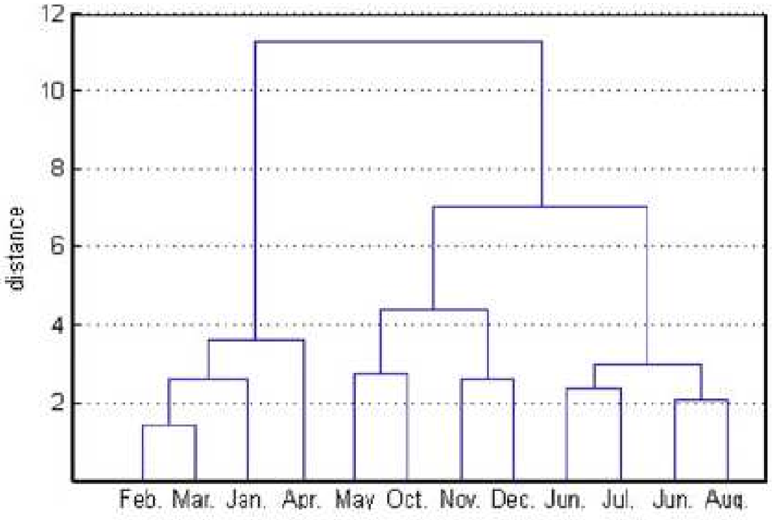

Figure 56: Tree diagram of temporal cluster analysis [31]

2) Fuzzy comprehensive assessment

Fuzzy comprehensive assessment (FCA) method can improve one’s understanding of the diverse processes and complex phenomena involved in environmental studies. FCA assesses the significance of each system-component in terms of predetermined weights and decreases complexity by means of membership functions [20]. For example, FCA can be used to estimate the relevant water quality variables.

3) Factor analysis

Understanding the ecological status of river systems is a difficult task given the various complex physical and chemical variables affecting water quality. Factor analysis (FA) is a multivariate statistical method that can be used to describe variability among observed variables. The observed variables are modeled as linear combinations of these factors plus some ‘‘error’’ terms [20]. Information gained about the interdependencies can be used later to reduce the set of variables in a data set. For example, FA can be used to assess a series of water quality indicators and their spatial variation.

4) Discriminant analysis

Discriminant analysis (DA) is based on already mastered information and historical data sample. It sums up the classification regularity of objectives, and then establishes a discriminant formula and criterion. When confronted with a new sample, as long as according to the discrimination formula and criterion, one can determine the category of the sample.

5) Principal component analysis

PCA is a powerful pattern recognition tool that attempts to explain the variance of a large data set of intercorrelated variables with a smaller set of independent variables. PCA extracts eigenvalues and eigenvectors (a list of loadings) from the covariance matrix of original variables to produce new orthogonal variables, which are linear combinations of the original variables. The principal components provide information on the most meaningful parameters that describe a whole data set allowing data reduction with minimum loss of original information.

In some cases (e.g. [20, 31, 54]), the researchers try to combine two or three statistical techniques to extract useful information among a huge data set. For example, in order to establish the natural and anthropogenic processes and factors responsible for enrichment of hydrological features, FA and CA are applied for three different sets of data i.e. total, fresh and saline influenced stations in Mahanadi river systems. CA was applied to the water quality data sets with a view to group the similar sampling sites (spatial variability) and resulted in a tree diagram; FA was performed on correlation matrix of rearranged data for three different water systems. This study which combined two statistic methods illustrates the usefulness of multivariate statistical techniques for evaluation and monitoring network for effective management of estuarine systems.

5.2.4 Modeling

An evaluation of the literature information collected demonstrates that the most used model is Soil and Water Assessment Tool (SWAT) (5%), followed by QUAL2E model, and the mass balance model (while total percentage is 7% for QUAL2E and mass balance model).

In principle, models provide essential tools for the management of catchments because they enable simulation of future pollution management strategies, climate change effects and land use change effects on water quality and quantity [32]. Next, the three most used models will be briefly described:

1) Soil and Water Assessment Tool (SWAT) is a basin-scale, continuous time model that operates on daily time steps and includes approaches describing how CO_2 concentration, precipitation, temperature, and humidity affect plant growth, meteorology, snow, and runoff generation. It has often been used as a tool to investigate climate change effects. During simulation, the climate, land use, soil, topography, and geological variations are all taken into consideration. This model is physically based, computationally efficient, and capable of continuous simulation over long time periods [14].

   There are numerous SWAT applications reported in the literature for hydrological and water resources assessment, in water quantity aspects (water discharge, groundwater dynamics, soil water, snow dynamics, and water management), water quality assessment (land-use and land-management change, best management practices in agriculture), and climate change impact. Several authors have also written reviews about the application of SWAT model [22].

2) The Enhanced Stream Water Quality Model (QUAL2E) is a steady state model for conventional pollutants in branching streams and well mixed lakes. It can be operated either as a steady-state or dynamic model and is intended for use as a water quality planning tool. The model can be used to study impact of waste loads on water quality and identify magnitude and quality characteristics of non-point waste loads [68].

3) The mass balance model is commonly used in emission approach to study source (point/non-point) contribution of pollution load into the receiving water bodies. The important aspect of water quality modeling is to determine the input loads to the river, that is, the total mass of material discharge per unit time into the river [57]. A mass balance, also called a material balance, is an application of conservation of mass to the analysis of physical systems. By accounting for the material entering and leaving a system, mass flows can be identified which might have been unknown, or difficult to measure without this technique. The exact conservation law used in the analysis of the system depends on the context of the problem but all revolve around mass conservation, i.e. that matter cannot disappear or be created spontaneously. Therefore, mass balances are used widely in engineering and environmental analyses.

   This approach is useful but is a simplification of the real processes, since several pollutants undergo physical, chemical and/or biological transformations during their transport from the origin to the water body.

5.3 Analysis of the methodologies used

5.3.1 Field monitoring

Environmental monitoring is used to provide a representative and reliable estimation on the quality of surface waters; this method is time-consuming and expensive. For example, in paper [51, 61], the monitoring included sampling ‘on foot’ and through an ‘auto sampler or handpicked’ while deepwater stations were sampled using a motorized boat. Without consistent monitoring, the results represent specific environmental conditions and cannot be extrapolated to other situations or to other parts of the river, lake or reservoir.

It was noticed that almost every paper described some natural conditions and characteristics of the lakes, rivers and reservoirs, but not all included data on the minimum, maximum or average water depths and river cross section or reservoir area. It is understandable that not all the researchers have enough sources to support a huge monitoring field system on. However, in order to provide a better understanding of the water mass, it is important to take these variables into account. Some examples are studies where the authors sampled the water at different depths at each monitoring sites [43, 80]; or where the water samples were collected at three points (1/4, 1/2 and 3/4) across the river width at all sites [54, 63].

Monitoring using water quality probes do provide immediate information, and are thus to be preferred for some tests. Specifically, pH and DO can change very rapidly in water once the sample is removed from the flow. Another problem is the preservation and transportation of samples. For example, in paper [41, 55], all the storage containers were anti-light and were pre-cleaned in high purity water to ensure minimum contamination. In paper [38], all samples were transported back to laboratory in an incubator with ice and saved with Na_2EDTA at 4 °C before sample extraction.

5.3.2 Modeling

It is known that modeling is a useful tool but the user is restricted to model options and assumptions, and models are often calibrated with a set of data that do not represent universal conditions. This means that a careful use of the methodology and critical discussion of results are crucial to the soundness of model application [19]. Next, some comments on the three mostly used models are presented:

1) SWAT model

SWAT is a public domain model actively supported by the U.S. Department of Agriculture Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA. It is a distributed, physically-based, watershed-scale model, incorporating considerations of the climate, surface runoff, soil type, vegetation growth and agriculture management in the modeling of the NPS load. In paper [14], the authors showed that this model is widely used in Northern America and in most developing countries in Asia including China, and then discussed how differences in conditions between North America and China can compromise model results when applied to China.

a) Empirical knowledge base required for process models

The user of the model inputs the slope, soil characteristics and land management practices of the study area into the model and the coefficients required by the model are automatically taken from the model knowledge base. The model then uses these values to calculate the runoff.

This process generally works adequately in the U.S.A because the model has been calibrated and validated in thousands of situations across this country. The vast amount of empirical information makes the parameters suited to the calculation of runoff under most situations in the U.S.A. In China there is little empirical data with which to validate the look-up tables and, as noted above, site characteristics in China are so different that much of the knowledge base contained in SWAT is not directly applicable in China for agriculture.

b) Calibration and validation

Runoff calibration in the Chinese application of SWAT is at the basin or sub-basin scale using hydrometric data from river gauging sites. These gauging sites are located at substantial distances downstream from headwater areas. The model calibration will produce correct runoff results at this large scale, but it is not known and cannot be determined, if to each different type of land surfaces upstream of the gauging station is given correct runoff values. Thus, the calibration used in Chinese applications only ensures that the aggregation of land use types produce the correct runoff at the scale of the basin area at the gauging station.

In Canadian studies SWAT has required extensive re-calibration for NPS estimations in areas. When the SWAT model is going to be applied to other countries, this means that a careful use and critical discussion of results are crucial to the soundness of model application.

c) Best management practices

Models such as SWAT are linked to a set of land management practices that are commonly used in Northern America. Few of these apply to agriculture in China due to vast differences in farm size, degree of mechanization, tillage practices, etc.

d) Artificial hydrology.

The application of dynamic models on flat areas such as the North China Plain is difficult insofar as there is little to no “natural” hydrology. All rivers are canalized with flow routed between artificial control structures both within and between river basins. For most of the year these rivers may be dry; when there is flow it is mainly wastewater from upstream point sources [14]. For all these reasons, attempts to use SWAT in this region of China have not worked well.

In summary, it is believed that a large amount of empirical verification will be required to adequately apply SWAT or any other dynamic model for NPS pollution estimation in China or to another country with a different reality compared to the U.S.A.

2) QUAL2E model

In paper [64], the author tried to set forth the limitations of the QUAL2E model. In the view of the author, one of the major inadequacies is the lack of provision for conversion of algal death to BOD, which is an autochthonous source of organic matter. In addition, the maximum number of reaches, computational elements, and junctions are limited in the currently available version of the QUAL2E model, meaning that the model cannot simulate large river systems with high accuracy.

3) Mass balance model

In paper [42, 57], the authors take rainfall distribution into account when using the mass balance model. As little or no rainfall occurs during the dry season the loads of monitoring locations should account for point loads. The total pollution load (point and non-point) of the water is assessed using the water quality and flow data of the wet season.

This method is useful just when the concentrations of pollutants do not change with time. Contributions from the atmosphere are neglected. Pollutant loadings and concentrations used in the model development are assumed to come from surface flow and wastewater discharge.

5.4 Possibilities for water quality evaluation using different approaches

Any chosen methodology for water quality assessment should be consistent and in accordance with the objective of the study. Sampling of water is an important issue in the water quality analysis and the monitoring locations should be chosen to provide a good area coverage as well as a good understanding of background water quality and anthropogenic sources of pollution. However, if the samples are not truly representative of the water, the results obtained, even from the most accurate analysis technique may be misleading. So, it is really hard to get comprehensive and representative water quality data; it requires a huge investment in time, human and material resources for field monitoring.

It is better to do an investigation including multi-year field monitoring in various spatial sampling sites for the study area. In order to investigate the potential pollutant sources within the watershed including sources of industrial pollution, urban domestic sewage, and agriculture pollution should be surveyed to acquire more comprehensive and representative data. However in most circumstances, the researchers always have some restrains, 3 common scenarios are the following:

Scenario 1: The researchers have limited time, money and human resources

There is a possibility to consult the local environmental protection bureau in order to have historic data for the case study area [e.g. 44]. It is not always available.

Scenario 2: The researchers have limited time, human resources but have sufficient funds

Setting up some auto water quality monitoring stations along the watershed, the researchers can get water quality data (e.g. pH, conductivity) from the in-place water quality multiparametric water probes.

Scenario 3: The researchers have limited money, but have sufficient time and human resources

For the purpose of collecting data concerning the water conditions of a given water mass, it is suggested that the researchers could enquire the local older inhabitants on the usual water conditions in different seasons and years. Another possibility is to search on the Internet to obtain some relevant data, including evaluation of land use changes over time.

After collecting the water quality data, if there is a huge amount of data, it is suggested that using the statistical methods will help the interpretation of complicated data matrices, a better understanding on the temporal and spatial variances of water quality will be reached.

Besides the evaluation of the water quality through sampling, it was found that there are four other types of sampling methods among the 57 references, and they also provide useful information to understand the condition of the water body.

1) Air sampling

Due to the growth in population, energy consumption, transportation and industries in recent decades, higher levels of volatile organic compounds (VOCs) have been observed in the urban atmosphere all over the world. If one wants to study the influence of the atmospheric input of VOCs on the aquatic environment, he/she should take the atmospheric deposition process into account. For example, once PAHs (a kind of VOCs) are emitted, they will be redistributed between gas and particle phases and removed from the atmosphere and deposited on the earth surface. During the past several decades, numerous studies have been undertaken to determine the level of PAH pollution in atmospheric deposition to aquatic environment. Normally, air sampling was carried out using a modified high volume air sampler with a certain flow rate adjacent to the deposition sampler. Then the bulk (dry and wet) particle deposition, air-water diffusion exchange, and vapor wet deposition of PAHs in an urban watershed can be estimated [39].

2) Sediment sampling

Sediments conserve important environmental information and are increasingly recognized as both carriers and possible sources of contaminants in aquatic systems. If one wants to access the impact of hazardous compounds (e.g. heavy metals, PAHs and etc.) to the water, because of their low water solubility and high partition coefficients, these compounds are strongly attached onto the surface of particles and tend to accumulate in sediments. Therefore, it is essential to collect and analyze the sediment samples.

In addition, it is interesting to compare the concentration levels of the targeted pollutant in water and sediment. For example, if the concentrations of the pollutants in the water are rather higher than the maximum background values in the sediment, this may mean that there is a consistent influx of effluents from the watershed nearby.

3) Phytoplankton sampling

Eutrophication has progressed in many aquatic ecosystems. Increasing nutrient inputs from surrounding watersheds is the primary driver of the cultural eutrophication. Among nutrients, Nitrogen (N) and phosphorus (P) have been considered as the main driver of the growth of phytoplankton [50].

In order to give guidance to water management, it is important to clarify the relationship between the phytoplankton biomass and the concentration of TN, TP. If one wants to evaluate the eutrophication process of a river, lake or reservoir, it is better not just to focus on the concentration of TN and TP. In fact, the researchers should also notice the phytoplankton blooms (phytoplankton biomass) and different phytoplankton species in the water during different seasons, especially in summer.

In addition, if one wants to study the heavy metals in a given watershed, it should be clear that the heavy metals not only exist in the water environment, they also accumulate in aquatic macrophytes. These organisms may remove the different metals from the water, therefore they can play a major role in reducing the effect of high concentration of heavy metals. Hence, if it is possible, the researchers should investigate the concentration of meals in aquatic plants as well.

4) Aquatic animal tissues sampling

The aquaculture industry is expanding in many regions of Asia, to produce wholesome food for human consumption. In order to control excessive algal growth and potentially disastrous phytoplankton blooms, the use of pesticides in aquaculture practices is essential to profitable production of aquatic animals (e.g. fish). The input of chemicals may cause the accumulation of pesticides in aquatic animal tissues [59]. Keeping in this view of point, it seems that to take samplings by dissecting the fish into different tissues is important, because when people eat fish, the concentration of pesticides in fish would directly influence the human’s health. It is noteworthy that this sampling method is more appropriate for confined water bodies, because in these cases researchers know the organism developed in that water mass during all live.

The authorities should give necessary guidance to farmers about the rational use of chemicals for better management of aquaculture and also monitor the chemicals used in fish farms in order to produce fish whose quality is suitable for human consumption.

It is suggested by the author of this study that the assessment of water quality should include two steps. Step 1: field monitoring; Step 2: statistical methods. Sometimes the last step does not make sense because the data is few.

At last, if the researchers consider the use of models, it is also suggested a search for models of free download from the website. In addition, modeling is a useful approach to understand present water quality conditions and to develop a decision support system of watershed management. An effective and economic strategy is to start with a simple model, then systematically increase its complexity, dividing the water mass into a larger number of segments area as dictated by hydrology and proximity to sources and available concentration data, and to introduce dynamic conditions. By following this strategy the complexity and rigor can both be guaranteed. The results of models should be compared to the results of actual water quality monitoring, this can show if the method is reasonable and suited to the case study

6. Final Remarks

The surface water quality is a matter of serious concern today in Asia as everywhere in the world. After analyzing 57 different studies it seems that the main reasons for the deterioration of water quality are the increase of the population and the industrialization that place a huge pressure on watersheds.

NPS and point source pollution always co-exist in most developing countries. As Table 13 shows, industrial, domestic and municipal wastewater discharges constitute the most common point polluting source. NPS pollution is caused by rain water flowing over the land surface and picking up and transporting natural and man-made substances such as from mining sites and agriculture field. This surface run-off is a seasonal phenomenon, largely affected by the precipitation pattern. Water dilution has a strong effect on river discharge and subsequently on the concentration of pollutants in rivers or confined water bodies.

Table 13: Number of studies from the 4 main countries cases that concern different kinds of pollution

	Industry	**Domestic**	**Municipal**	**Mining**	**Agriculture**	**Other sources**
China	7 #	5#	1#	1#	8#	2#
Japan	2#	1#	0#	1#	6#	1#
India	7#	7#	3#	1#	4#	4#
Korea	6#	3#	0#	0#	5#	0#

It is important to consider the environmental conditions at the watershed before analyzing a given river, lake or reservoir. As discussed in Chapter 1.3, the researchers ought to take the general climatic conditions, geography and land use of the study area into account.

First of all, it is important to make clear how much is the annual precipitation during the year time (precipitation data can be gathered from several nearby meteorological stations), how is the yearly average temperature (data can be gathered from meteorological agency), the different patterns in the dry season and the rainy season, how long is the monsoon months and non-monsoon months in each region, etc. For example, during the rainy season, pollution discharge is mainly influenced by the flow rate. At the initial stage of rainfall, peak concentration of organic matter comes out before peak flow rate in every rainfall events. Hence, it is necessary to investigate and manage the first flush in order to control pollutants from NPS. Only understanding these climate factors, one can find a correct time and places to do field monitoring.

Secondly, the researchers should understand the geographical conditions in one area. For example, in order to assess the effect of human activity, the researchers should investigate the existence of industrial complexes, urban households, and mining sites. Meanwhile, it is important to know the terrain of NPS. For instance low-lying paddy fields are risky to the environment in the rainy season since paddy water normally flows out into the surrounding bodies of water and become NPSs of pollution. On the other hand, under some situations, natural factors that regulate water quality such as the nature of surface rocks exposed for interaction with water, may increase the concentration of heavy metals in the water. It seems that water quality is also related to geological factors (influence of scour of rock).

Last but not the least, to make it clear the dominate soil type, what is the land mainly used for. For example, if an area in the city is undergo extensive land conversion from agricultural use to urban-industrial-commercial use, and then it is noteworthy to consider the point source pollutant during the whole year.

Many studies mentioned that rivers, lakes and reservoirs are important for agricultural and other economic activities and are the main source of drinking water for the population. In most developed countries it is mandated by law that the citizens should be given clean and abundant water. Dams, reservoirs, filtering plants, and pipes all bring clean water. Drinking water resources should be unpolluted and safely enough. Once these drinking water resources get severe polluted, for example by bacteriological contamination (e.g. total coliform), heavy metals and POPs (e.g. pesticides and PAHs), poor quality of drinking water can cause illness (include infection from bacteria or by small parasites), and even death of residents. More than 60% of developing countries' rural populations (more than 2 billion people, in 2004) [78] lack access to sufficient amounts of clean and safe water (WHO-UNICEF 2006) [92]. Meanwhile, the government may pay a high-cost of treatment for drinking purpose and cure diseases of the residents. In the absence of national laws, it is better for every Asian country to follow the guideline values for drinking water quality from the WHO to protect the drinking water resources. If a certain country has more restrictive laws and regulations, it can make a better management according to local law.

In view of the spatial and temporal variations in the hydrochemistry of watershed, regular monitoring programs are required for reliable estimates of the water quality. This results in a huge and complex data matrix comprised of a large number of physico-chemical parameters, which are often difficult to interpret and draw meaningful conclusions. Thus, analyzing data with statistical analysis (e.g. PCA, CA, DA and etc.) is an important way for processing of water quality parameter and a useful tool for classification and identification of possible sources of pollution.

In addition, applying models could be an efficient way to estimate contributions of all identified pollution sources to each water quality parameter. For example, in the SWAT model, the hydrology processes simulated include surface runoff estimated using Green-Ampt infiltration equation; percolation is modeled with a layered storage routing technique combined with a crack flow model; potential evapotranspiration modeled by the Penman-Monteith methods; snowmelt; transmission losses from streams; and water storage and losses from ponds are also processes that can be included[22].

This study just focused on the water quality issues in Asian countries and tried to analyze the most relevant problems and the methodologies used for assessment of the water quality. There are some limitations in this study, for example the time duration of three months, and the fact that the author has never been involved in experimental studies of water quality.

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