Problems of Groundwater Extraction from Transboundary Aquifers and Complexes

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Abstract. Water is one of the most important vital types of natural resources used in almost all spheres of life and human activity. It is the availability of water that determines development of industry and agriculture. Its selection and irretrievable losses can have a significant impact on the state of the natural environment. Geology of the earth's surface is arranged in such a way that boundaries of groundwater aquifers and complexes distribution do not coincide with the boundaries of states, and therefore extraction of this priceless resource must be regulated at the international level. The development of a unified universal concept for groundwater production, namely the system of state regulation, monitoring, taxation and planning should be based on the experience of advanced countries such as Russia, Germany, France, etc., where a vast experience of scientific and research activity is accumulated. Many international conflicts can be prevented if one approaches the problems of subsoil use on the basis of a general agreement. The aim of the research is development of an international conceptual model for groundwater production management through regulation of specification systems, monitoring, licensing, control of groundwater extraction. Features of groundwater extraction from transboundary aquifers are considered, international experience of conflict regulation in this sphere is reviewed, recommendations and prerequisites for the development of an international system for the groundwater extraction management are given.

1. Introduction

Groundwater is an important component of the natural water system. Groundwaters are extracted from aquifers and used for drinking and household purposes, in agriculture and production [1]. Groundwaters belong to the category of strategic minerals, along with hydrocarbon resources, so the supply of drinking water will be one of the pressing problems of modern society. According to UN experts, by 2030, about half of the world's population will suffer from a shortage of fresh water, and this can lead to future military actions and conflicts [2].

In this connection, extraction of such valuable minerals as groundwater must be managed rationally. On a combination of a reasonable selection of groundwater with observing the norms of their quality, the concept of "rational use of them" is based. That is, under the rational use of groundwater it is recommended to understand their economically feasible operation, which provides protection from pollution and depletion of operational (mineable) reserves and allows to maintain groundwater resources and environmental conditions at a given level [3].

Over-limited extraction of groundwater and, at the same time, inefficient use cause a rapid depletion of groundwater resources in many countries [4]. In addition, both natural processes and human activities can have a significant impact on groundwater quality and future constraints as a source of water supply. In view of such natural and anthropogenic reasons as population growth, unplanned
urbanization, economic development, the amount of groundwater continues to decrease. Therefore, strategies for sustainable management of groundwater production are required. In turn, development of a proper groundwater management strategy requires the study of aquifers characteristics, spatial and temporal groundwater monitoring [5].

Worldwide, about 60% of all freshwater runs within cross-border basins; only an estimated 40% of those basins, however, are governed by some sort of basin agreement [6]. In an increasingly water-stressed world, shared water resources are becoming an instrument of power, fostering competition within and between countries. The struggle for water is heightening political tensions and exacerbating impacts on ecosystems [7], [8].

By its nature, beneficial and rational use of groundwater depends more on socio-economic, institutional, legal, cultural, ethical and political considerations than surface water. Their national development is hampered by weak social and institutional capacity, as well as by weak legal and policy frameworks. In a transboundary context, this can be further strengthened due to contrasting levels of knowledge, opportunities and institutional frameworks on both sides of many international borders [9].

Despite their significance, physical interactions between surface and groundwater have largely been ignored in international water law. While surface water has been given considerable attention as a transboundary natural resource, groundwater has not received the same recognition. International legal doctrines regarding water, such as the 1997 United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses, only recognize one aspect of groundwater, excluding confined aquifers. While the issue of transboundary groundwater in international treaties is becoming increasingly relevant as disputes over groundwater resources come to the fore, it is usually only indirectly mentioned in treaties. Groundwater and surface water should be considered together as part of the hydrological cycle and reflected as such in the legal body. The uncertainty of physical properties is not an excuse for the delay of a concrete framework. An Interactive Coordinated Approach (ICA) is recommended as a guideline for future implementation of transboundary groundwater management [10], [11]. The purpose of this research is to demonstrate the need to develop comprehensive transboundary groundwater management conceptual model.

2. Materials and Methods

2.1. Peculiarities of Transboundary Aquifers

Many of the world's existing groundwater systems (or "aquifers" - so called usable groundwater reservoirs) are transboundary, that is, they lie on the territory of two or more administrative units within the country or two or more countries. Obviously, in the second case, administrative and operational management of groundwater resources is facing additional challenges and requires harmonization of rules and transboundary cooperation between various bodies involved in groundwater mining, based on mutual trust and transparency. There are still not many examples of such cooperation in the world.

The main features of transboundary aquifers are such factors as feeding and discharge areas, extensive distribution, interconnection with other aquifers and open water bodies (Figure 1). In many cases, aquifer may have a catchment area in the territory of one state, and the water discharge area is located in the territory of other border states. Such schemes are common, as a rule, in submontane and foothill-flat areas. This is typical, for example, for Austria - the Czech Republic, Germany - Poland, Switzerland - France.
Very few international borders correspond to natural physical features, and water resources can cross them without hindrance. To effectively manage and equitably distribute these resources, scientists assess the resources that cross these boundaries. In hydrogeological terms, these crossing resources can only be estimated by observing and measuring individual hydraulic parameters, similar to the process of assessing other transboundary resources.

There are marked differences in the status of the recognition for transboundary surface water and groundwater. Consequently, transboundary groundwater directives have been omitted from overall water management regulations. The two primary reasons for this absence are also points of contention in transboundary groundwater management. First, groundwater characteristics vary in each aquifer. Groundwater is often deep or unevenly distributed geographically. These uncertainties make groundwater seemingly impossible to regulate, as well as ill defined. The other reason is the transboundary element. Dealing with transboundary issues has been intensively studied in surface water; as a result, the difficulties as well as the necessity for management structures are understood. By contrast, in terms of transboundary groundwater, even the delineations of an aquifer are a challenge. Under the best use of monitoring and modeling techniques to identify groundwater characteristics, the definition of an aquifer cannot provide concrete conclusions about groundwater ownership. Because of these difficulties, in addition to the rapidly increasing population and the rising demand for water, groundwater quality and quantity have become serious environmental, economic, political, and socioeconomic concerns. Therefore, the establishment of an apparent management framework is critical [11].

Even where international borders can follow signs such as rivers and aquifers underlying them, they may not reflect the true transmission of groundwater flows from one side to the other, as it is shown in Figure 2.

Surface waterways, such as rivers and lakes, are regulated by the European Water Framework Directive. All kinds of activities are clearly regulated by international laws. But, extraction and use of groundwater, due to a certain specificity and diverse legislative base, often do not have a single universal management model.
2.2. Transboundary Aquifers Regulation

In any legal agreements that should be drawn up for the management of transboundary resources, the initial stage should be the correct definition of the flow and movement of water with subsequent quantification. Institutional weakness and political pressure may not solve all relevant issues, which can lead to serious consequences for the environment and unsustainable development. Current growing problems with respect to the quality of groundwater resources and sustainability of groundwater abstraction levels acquire a special political connotation when groundwater flows across the international border of states and, as a result, becomes a "common" resource. Sensitivity to sovereignty, diversity of legal and socio-political systems and various national programs cause certain difficulties. This is exacerbated by the fact that none of the internal "water" laws of neighboring countries can provide acceptable universal management rules. Consequently, such rules must be found elsewhere, that is, in treaties and agreements between interested sovereign states, or in case of non-observance of such treaties and agreements, in the consistent practice of the states themselves [9].

The problem is the following: nowadays there are very few treaties and agreements that provide unified international rules for managing groundwater extraction, as well as protection of common groundwater resources. Particularly acute this problem affects states with a shortage of water resources (countries in Africa, Central Asia, the Middle East, some countries in Europe and North America). Figure 3 illustrates an overview of global transboundary aquifers made by TWAP (Transboundary water assessment programme) [12].

A clear need has been identified for an international initiative on Internationally Shared/Transboundary Aquifer Resources Management. The International Association of Hydrogeologists (IAH) established a Commission to investigate the issue in 1999. A meeting of experts was held in parallel with the International Conference on Regional Aquifer Systems in Arid Zones – Managing non-renewable resources organised by UNESCO in Tripoli 20–24 November 1999. The results of the consultation indicated the need to create an international network supported by IAH, UNESCO, FAO and UNECE. Therefore with the support of UNESCO and IAH in co-operation with FAO and UNECE a meeting of experts was held at UNESCO in Paris 27–28 March 2000. As a result of the meeting a programme proposal for an international initiative on internationally shared/transboundary aquifer resources management (ISARM/TARM) has been tabled [9], [12].
Figure 3. Overview of global transboundary aquifers made by TWAP [12].

Since its start in 2002, ISARM has launched a number of global and regional initiatives. These are designed to delineate and analyze transboundary aquifer systems and to encourage riparian states to work cooperatively toward mutually beneficial and sustainable aquifer development. The ISARM portal is developed and maintained by IGRAC (International Groundwater Resources Assessment Centre) [9], [13].

3. Results and Discussion

Thus, at present legal issues regarding quantitative factors of groundwater extraction from transboundary aquifers and systems are not fully resolved. There is a huge number of countries that have encountered problems regulating the use of transboundary groundwater resources. For example, the extraction of groundwater from the aquifer of Trifinio - by the name of the region where the borders of the three countries: Guatemala, Honduras and Salvador meet. The most serious problem related to water management in the region is pollution. According to the estimations of the experts of the project GRGTA (Groundwater Resources Governance in Transboundary Aquifers), which is part of the program "Diplomacy and Water Management in Key Problem Transboundary Areas" and funded by the Swiss Agency for Development and Cooperation under the UNESCO International Hydrological Program (IHPE UNESCO), in close cooperation with the UNESCO International Center for the Assessment of Underground Resources Water (IGRAC), the International Union for Conservation of Nature (IUCN) and project teams on the ground, in the absence of effective monitoring, the level of groundwater pollution here of time will only increase [14].

The lack of monitoring data (climate, as well as data on groundwater abstraction, water levels and quality) makes it very difficult to conduct systematic diagnostic analysis. Such a problem has arisen in the Stamprietta system of transboundary aquifers, located in a vast arid region in Central Namibia, Western Botswana and the Northern Cape of South Africa [14].

The Pritashkent transboundary aquifer (PTTA), located on the territory of Kazakhstan and Uzbekistan, causes the following problems: inevitable depletion of groundwater resources as a result of their selection. In the long term, groundwater level may drop below a level that is minimally necessary for exploitation from a technical or economic point of view. The decrease in the piezometric level of PTTA will quickly spread in breadth, including beyond the interstate border. Another major problem is potential deterioration of groundwater quality. The gradual lowering of water level in the transboundary aquifer may lead to the infiltration of brackish and saline groundwater from the overlying aquifers. Finally, contamination of the upper aquifers can lead to the abandonment of their use and transition to water intake from PTTA [14].

Of the twelve million people who live within 100 km of the US-Mexico border, 90 percent are clustered in trans boundary sister cities that share common water sources and pollution problems. New
institutions created to address environmental concerns over North American Free Trade Agreement (NAFTA) offer the promise of greater financial and technical assistance for water management in border cities. Diversity and geographic dispersion of water conflicts presupposes the possibility of applying an interrelated approach to water negotiations between the United States and Mexico. Back in 1973, Mexico and the United States reached an agreement on specific volume restrictions on the annual production of groundwater in the territories of both countries, within eight kilometers from the international boundary of Arizona-Sonora. In addition, the agreement requires that the two countries consult each other before any new development or substantial modification of both surface and groundwater resources on their territory in the border zone, which could adversely affect another country \[15\].

The absence of a common reciprocal management system for groundwater extraction from transboundary aquifers and complexes leads to numerous conflicts, including military actions in the territory of Israel, Palestine and Jordan.

For the North-West Federal District of Russia, this problem is relevant for groundwater operation from transboundary aquifers, which is relevant to their operation by neighboring countries - Estonia, Latvia, Lithuania, Poland, Belarus, Finland and Norway. First of all, this is due to the lack of information on the volumes and regime of groundwater production in adjacent territories, as well as the possibility of joint planning for further exploitation of aquifers.

This is not a complete list of examples of the lack of cooperation between states that exploit "common" groundwater resources and resulting disagreements. There are other agreements, in particular in Europe, that cover groundwater resources within a broader framework for cooperation in the management and protection of bordering rivers or in their development. However, groundwater plays an insignificant role in these agreements.

Thus, problems of groundwater production from transboundary aquifers and complexes are:

1. Absence of a unified international system for managing the extraction of groundwater as a particularly valuable type of minerals.
2. Attempt of local, as a rule short-term, laws and by-laws regulating the system of groundwater extraction management from transboundary aquifers. In this case, directives and framework agreements are adopted in each specific situation.
3. Scale of the problem, which lies in the field of its operation. The problem concerns any border subsoil use, in contrast to surface water bodies and streams, which are regulated by the European, Asian and other water directives \[16\].

During the identification of these problems, it is proposed to use the existing experience of managing groundwater production in Russia, Germany, France and other developed countries to create a unified international concept for managing groundwater production from transboundary aquifers and complexes.

The international management model implies development of a mechanism based on:

- uniformity of the licensing procedure for groundwater extraction (mining permits for individuals and legal entities);
- compatibility of the monitoring system based on uniform standards and reporting on the extraction of groundwater with identification of the main relevant parameters (factors such as dynamic parameters of heads when groundwater reserves are developed, periodic reporting of chemical and bacteriological analyzes);
- access to subsurface resources for all categories of water users with common subsoil use rules for transboundary aquifers;
- unification of the system for planning the development of groundwater deposits, including domestic, drinking, technical, medical and energy purposes based on modern numerical models, allowing complex, real-time analytical calculations (for example, as in Germany);
- system for financing the above systems by optimizing the taxation system (a tax on the extraction of minerals, as an effective way of managing the development of a groundwater deposit) and at the expense of state budget sources;
planning geological exploration for both existing and poorly studied groundwater deposits, including the creation of a network of observation wells and facilities included in the network of a unified monitoring system using modern remote observation technologies;

- calculation of the limits of influence on transboundary aquifers, the level of critical aquifer operation;
- opportunities for supporting poor countries to provide access for specialists to build observing systems, to identify opportunities for restrictions on groundwater production volume;
- control over the target consumption of groundwater resources, which is especially important for aquifers with difficult water exchange or for unique deposits of medicinal mineral waters.

This model should be built on the basis of interstate agreements based on specific local legislation of individual countries, but within the framework of a single concept.

Advantages of the proposed model:

- simplicity;
- openness;
- understandability;
- universality (using numerical modeling);
- availability (low-cost implementation).

4. Conclusion

The world's groundwater resources have a key importance for sustainable development. Utilizing the full resources of groundwater and effective control of the perennial problems associated with groundwater, such as excessive use and pollution, are very complicated tasks. The exchange of information and experience in the groundwater production management around the world will be necessary and extremely useful in this regard [13].

Aquifer resources management, aiming at the responsible exploitation and adequate protection of the groundwater resources, is therefore of key importance and has to be based on sound hydrological, environmental, economic and social principles. In order to accomplish groundwater resources management goals in the case of transboundary aquifers, a balanced joint strategy is needed [17]. However, practice has shown that management of groundwater resources and their protection is a very difficult task. Groundwaters interact with other components of natural environment and are exposed to them. Often, there is only the most limited knowledge of local groundwater systems and their behavior; In addition, each groundwater system usually unites a multitude of consumers and other parties that often compete or conflict with each other. Adequate administrative measures for information systems, institutions, policies and various forms of support are required for effective measures to manage the extraction of groundwater resources.

5. References

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