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HYDROLOGICAL MODELING IN ENVIRONMENTAL HEALTH: ROLE, SIGNIFICANCE, AND COMPARATIVE ANALYSIS OF APPLICATION METHODS

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ABSTRACT

Water is one of the most important factors affecting life and environmental health. Therefore, estimating the behavior of water in nature makes it easier to take precautions for pollutants that affect environmental health and to prevent such problems. At this point, to estimate the behavior of the water, the hydrological cycle should be evaluated on a watershed basis and hydrological modeling methods are needed within the framework of climate projections. Nowadays, many different softwares are used for the creating of these models. This software evaluates various climatic and hydrologic parameters such as flow, precipitation, wind, temperature, solar radiation according to the application methods, as well as need topographical components such as slope, elevation, aspect of the study area, and terrain features such as soil characteristics and land use. Hydrological modeling software plays a significant role in the prediction and monitoring of problems such as poor water quality, pollution, particle and sediment transport, diffusion of oil and petroleum derivatives, and microplastic distribution, which are frequently encountered in environmental health.

Within the scope of this study, information about the usage potentials and data requirements of hydrological modeling software in the field of environmental health is given and among them, the advantages and disadvantages of the most preferred software on the global scale, SWAT, WEAP, MIKE Zero, Delft3D are discussed comparatively. The findings are presented in the form of suggestions for the management planning of environmental health and its integration into decision support systems.

1. Introduction

Protecting the balance of behavior and quality of water, which interacts completely with life and nature, has great importance for the sustainability of environmental health. Maintaining this balance is equivalent to protecting life. However, mechanisms that can disrupt the balance and the effects of these mechanisms should be determined quickly and necessary precautions should be taken against possible negative effects. Hydrological models are used effectively in the detection, monitoring, and analysis of the system that includes problems, such as poor and deteriorated water quality, pollution, particle and sediment transport, the spread of oil and petroleum derivatives, and microplastic distribution. In this study, information about hydrological models will be given and the advantages and disadvantages of using hydrological model software in the environmental health field will be examined.

2. The Behavior of Water in Nature

The behavior of water, which forms the basis of life on earth is in the form of a cycle called "Water Cycle" or "Hydrological Cycle". This cycle can be defined by movements such as evaporation of water into the atmosphere, returning with precipitation, infiltration, discharge as a spring and stream, and flowing into a lake or sea (Figure 1).

Considering the water behavior on a basin basis, the inflow to the system occurs with rainfall or snowmelt, while the outflow from the system is as streamflow and evaporation-transpiration. The precipitation

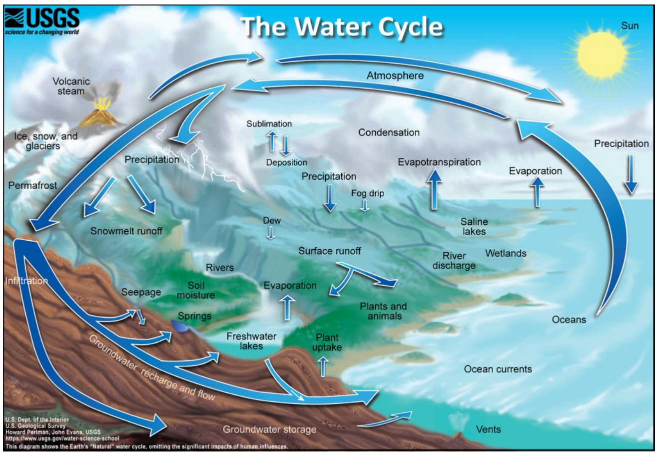

Figure 1. The water cycle (14)

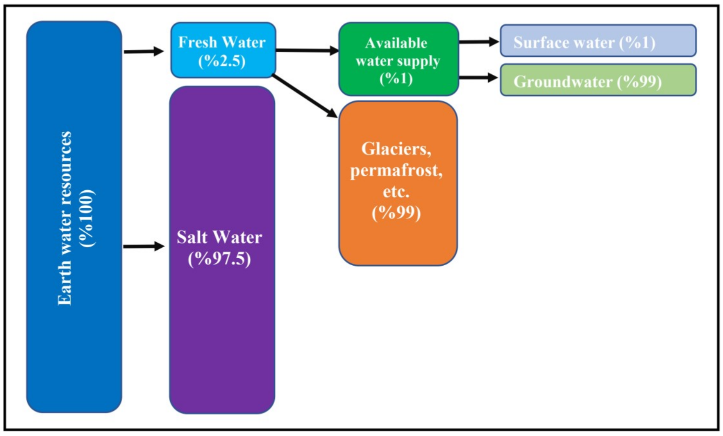

Figure 2. Global water distribution

reaches the streams by mixing with the tributary channels through the overland flow, and by interflow and baseflow following infiltration into the soil (6).

The presence of water on earth, which is the sum of the hydrological cycle components, has been calculated as approximately 1.4 billion km³ (14). If the ocean and sea waters that make up 97.5% of this water are left aside, only 2.5% is available as freshwater. Groundwater and surface water constitute 1% of freshwater as a usable water source (Figure 2).

Freshwater sources are highest in Asia, South America, and North America continents. However, the water resources and the population were not evenly distributed on the continents (Table 1). Considering the amount of water per capita, especially in Asian, African, and European continents, the probability of encountering water-related problems is high.

Since the geographical location of Turkey is located at the intersection of these continents, the amount of available water per capita was 1652 m³ in 2000, 1544 m³ in 2009 and, 1346 m³ in 2020 (3). According to the Falkenmark indicator, which is among the most frequently used indices to compare the water resources of the countries with each other, Turkey is situated in the category of countries under water stress (Table 2).

According to the Turkey Statistical Institute (TUIK) population projection, the population of Turkey was calculated as 100 million in 2040 (13). Therefore, if the water resources are not protected, the water index value will be less than 1000, and Turkey will fall into the category of countries with water scarcity. With the population growth, the protection and sustainability of water resources have great importance in protecting the environment and human health.

3. The Importance of Water for Environmental Health

Water, which interacts with all life in the cycle where natural phenomenon affect completely, is the most

Table 1. Distribution of Water Resources on Earth (1)

Continents	Population (%)	Water resource (%)
North America	8	15
South America	6	26
Europa	13	8
Africa	13	11
Asia	60	36
Australia and islands	1	5

Table 2. Falkenmark indicator (5)

Interval (person m³/year)	Classification
> 1.700	No stress
1.000 – 1.700	Stress
500 – 1.000	Scarcity
< 500	Absolute scarcity

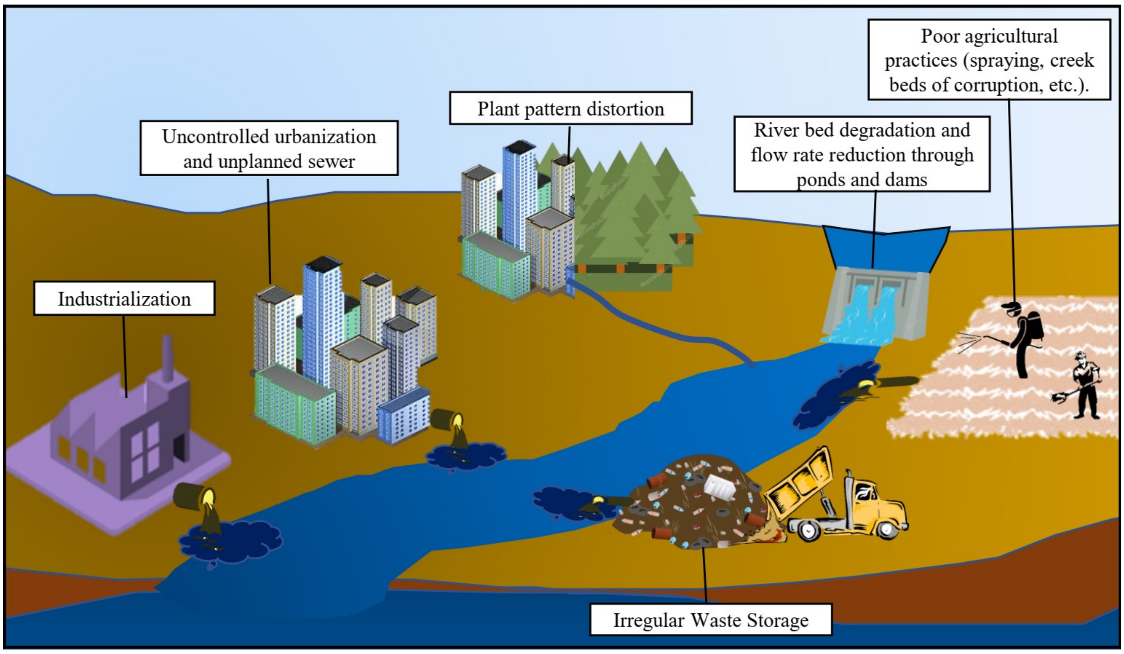

Figure 3. Pollution sources that affect water quality

important transport medium in the earth. With this transportation feature, while it touches all the environments on earth, water pollution occurs when the factors that negatively affect environmental health are included in the water cycle. Apart from natural changes, these largely anthropogenic based factors include structures such as dams and ponds that prevent overland flow, poor agricultural practices, carbon emissions, plant pattern changes, unplanned urbanization and industrialization, and irregular waste storage and uncontrolled sewer discharges. Disposal of industrial, agricultural, and domestic wastes generated as a result of all these activities by rivers disturbs the natural water balance and reduces the biological, physical, and chemical quality of the water (Figure 3).

Therefore, monitoring the behavior of water facilitates to ensure the sustainability of urban and natural life and to take precautions for the pollutants that affect environmental health and to prevent the problems to be experienced. In this context, the multidisciplinary study between environmental health which aims to improve the environmental conditions, and hydrology which discusses the determination and monitoring of water quality, and removing water pollution provides quick solutions for the problems that can be encountered (7,8).

4. The Role of Hydrological Modeling in Environmental Health

Hydrological models are tools that allow complex surface water systems to be solved mathematically in the most realistic way by simplifying them with some assumptions. Since these models, in which water quality parameters can also be integrated, can also simulate the distribution of pollution, they become important for the estimation of the distribution of the pollutants in the water and determining the future steps to be taken for the water-environment pollution without large-scale chemical analysis and labor force even in areas that are difficult to access (10).

Nowadays, many different softwares are used to develop and analyze these models. After the problem is defined and the software is selected, the hydrological model development is conducted with the steps given in Figure 4.

First of all, a conceptual model that represents the natural behavior and processes of the hydrological system on a regional or basin basis should be established. Then, mainly, various climatic and hydrological data such as flow, precipitation, wind, temperature, solar radiation, etc. and according to an analysis of the software, topographical characteristics and soil properties such as lake/river bathymetry, slope, elevation, aspect, and land use characteristics

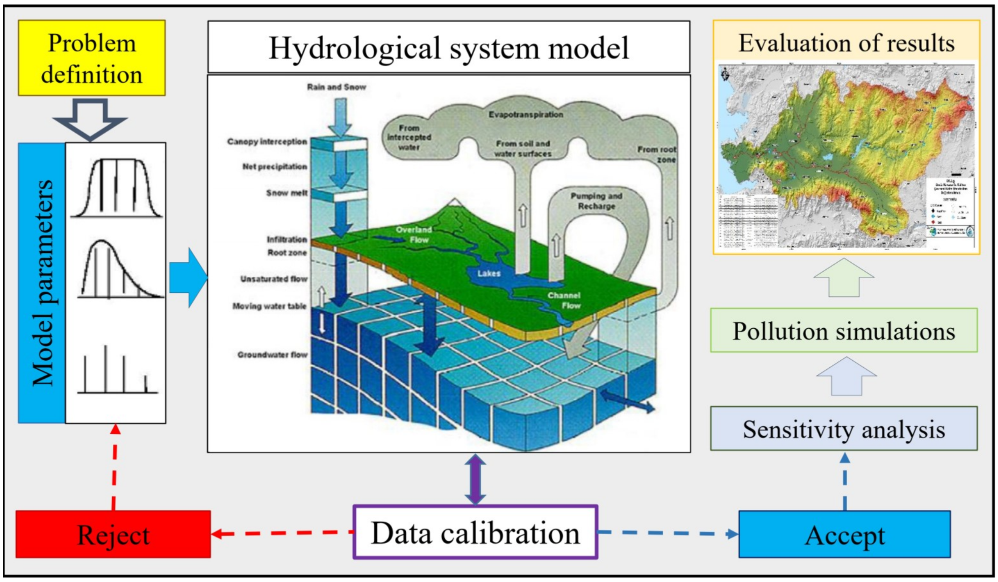

Figure 4. Simplified Hydrological Model Development (Modified from (12))

should be defined to model. Afterward, the calibration process should be continued until a good match between the observed and simulated values is achieved. If the calibration is successful, sensitivity analyzes are performed to understand the effect of the parameters on the model. After the hydrological system model is completed, with the assignment of parameters to model related with water quality and pollution, particle and sediment transport, diffusion of oil and petroleum derivatives, microplastic distribution, it is possible to observe current and future distribution and effects of pollutants. This makes hydrological models an important and necessary tool for environmental health. At the same time, the use of hydrological models is in the role of supporting the relevant national communiques and regulations determining the environmental standards of water quality and legal legislations such as the European Water Framework Directive. In this way, it will enable environmental health researchers to become part of the relevant legal legislations and applications such as the National Water Plan and watershed management plans. Since hydrological models facilitate decision-makers to solve problems more accurately and effectively, water and environmental health employees will be able to design their decision

Table 3. Areas of usage of the hydrological model software

Dimension	*Model type*	*SWAT*	*WEAP*	*MIKE*	*Delft3D*
1D	Water quality and pollution	a	a	a	a
	Hydrodynamics	a	a	a	a
	Propagation - distribution	a	a	a	a
	Hydrology (rainfall-flow)	a	a	a	a
	Sediment transport	a	a	a	a
2D	Water quality and ecology	a	a	a	a
	Hydrodynamics	a	a	a	a
	Propagation - distribution	a	a	a	a
	Sediment transport	a	a	a	a
	Microplastic distribution	r	a	a	a
	Particle monitoring	r	a	a	a
	Oil & petroleum derivatives	r	a	a	a
3D	Water quality and ecology	r	r	a	a
	Hydrodynamics	r	r	a	a
	Propagation - Distribution	r	r	a	a
	Sand transport	r	r	a	a
	Sediment transport	r	r	a	a
	Microplastic distribution	r	r	a	a
	Particle tracking	r	r	a	a

support systems and ensure that they are included in all water-related decision support systems. In the solution of these problems, the usage areas of SWAT, WEAP, MIKE Zero, and Delft3D hydrological modeling software, which are the most preferred software on a global scale, are given in Table 3, and their potentials, data requirements, advantages, and disadvantages in the environmental health field are given below in detail.

4.1 SWAT:

SWAT, developed by the University of Texas A&M (TAMU) as free software, is a river basin scale model used to estimate the quality and quantity of surface and groundwater and the environmental impacts of land use, land management practices, and climate change. It develops 1-D and 2-D models for the soil erosion prevention, and control, nonpoint source pollution control, and assessment of regional management in basins. For the development of the model, land characteristics such as topography, land uses and soil properties, hydrological data such as discharge flows, water levels, and meteorological data such as precipitation, temperature, and solar radiation are required. While rapid model development, user-friendly interface, easily accessible data requirement, and Geographic Information Systems (GIS) solution support are among the advantages of this software, not to conduct 3-D models and water quality monitoring can be considered as disadvantages (9).

4.2 WEAP:

WEAP, which is developed by the Stockholm Environment Institute (SEI), is licensed for a fee while it is free for a non-profit, governmental, or academic organization based in a developing country. This software develops 1-D and 2-D models to support expert planners for integrated water resources planning. Climatic data for the basin, flow chart and flow rates, bathymetric values of water bodies, discharge, and recharge flows, and amount of pollutant sources are the input data for the software. This software can develop models for sectoral demand analyzes, water protection, water rights, and allocation priorities, reservoir operations, hydroelectric generation, pollution monitoring, and water quality, vulnerability assessments, and ecosystem requirements. It is among the advantages of the software that the model setup can be realized quickly, has an easy-to-use interface and easy data collection, provides GIS support, and enables model scenario editing. However, this software does not offer the opportunity to model in 3D (11).

4.3 MIKE Zero:

MIKE Zero, which is paid license software, created by the Danish Hydraulics Institute (DHI) and capable of modeling in 1D, 2D, and 3D according to the hydrodynamic properties of the water. For the model development, land characteristics such as topography, bathymetry, land use and soil properties, hydrological data such as discharges and flow rates of stream and point sources, water level, flow rates, water salinity, and temperature and meteorological data such as wind, precipitation, temperature, and solar radiation are required. This software can be used for solutions to pollution problems such as environmental pollution, particle, and sediment transport, diffusion of oil, and petroleum derivatives. While MIKE Zero has advantages such as being able to make develop models in all dimensions, providing GIS support, and applying model scenario editing, it requires relatively difficult to achieve inputs such as bathymetry and wind data and has relatively expensive license fees. Additionally, since the model interface is not user friendly, the model development is complicated (4).

4.4 Delft3d:

Delft3d, which is developed by the DELTARES, requires morphological data (topography and bathymetry), land and soil properties, amount of water pollutant, hydrological data such as water levels and flow rates, and meteorological data such as wind, precipitation, temperature, and solar radiation. This software consists of different modules and develops models in 1D, 2D, and 3D. Some application areas of this software are flow due to tidal, wind, density gradients, and wave-induced currents, propagation of directionally spread short waves over uneven bathymetries including wave-current interaction, wastewater disposal, morpho-dynamic calculations, cohesive and non-cohesive sediment transport, water quality phenomena including ecological modeling, heavy metal pollution, interaction with organic and inorganic suspended and oil pollution. This software, which can develop models in all dimensions, supports GIS analysis, can be used in the solution of all water quality problems, and enables model scenario editing applications. However, it needs bathymetry and wind inputs, which can be relatively difficult to access, as in MIKE Zero. Delft3d Model development is not easy with moderate ease of use and although source code is free for students, it has relatively expensive license fees (2).

5. Conclusion

Water has indisputable importance for human and environmental life sustainability now and in the future. Therefore, prediction, determination, monitoring, and solution of the environmental problems that may occur in the water cycle should be done most reliably and rapidly. Hydrological model software, which is the product of today's technology, is one of the most suitable tools that can be used for this purpose. It will provide cost and time savings with the results that it will produce from the available data even in difficult to measure parameters. To use this software, firstly, a suitable one should be chosen according to available data, and problem considering the advantages and disadvantages, and then, with the selected one, the analysis should be carried out with correct assumptions and good planning. SWAT, WEAP, MIKE Zero, and Delft3D software are frequently used on a global scale to solve various water-related problems. Therefore, using this software will help environmental health researchers to design their decision support systems by providing effective, accurate, and easy decision making at the solution stage of the water-related problems, and it will be possible to integrate them with other decision support system in the fields of health and life sciences for the water-related issues. Also, using model software in the process of water quality monitoring will support the relevant national communique and regulations that determine the environmental standards of water quality and legal legislations such as the European Water Framework Directive. At the same time, it will make great contributions to the field of environmental health in the short and long term by ensuring that environmental health researchers take an active role in the preparation of the National Water Plan and watershed management plans in which these legal regulations are applied.

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