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Introductory Chapter: Hydrologic Science - Where We Stand Today?

Muhammad Salik Javaid and Laila Khalid

1. A journey through ages

Much has been written in the scientific literature about this diverse field of hydrologic science. However, this chapter is aimed at introducing modern hydrology, highlighting its evolution from ancient times to the recent era of rationalization, theorization, and computerization. Though hydrology is a main branch of science, it has exhibited very slow but steady developmental strides as compared to some other branches of science showing quantum leaps. Discussing the historical development of hydrology, it can be divided into [1] six successive periods of time: (a) ancient hydrology (1000 BC–AD 500), (b) medieval water technology (500–1500), (c) renaissance concepts and measurements (1500–1700), (d) the emergence of water science (1700–1800), (e) the era of empirical hydrology (1800–1930), and (f) rationalization, theorization, and computerization (1930–2000).

Hydrology is the science of water came into being the day the first winds blew across the meadows, the day the first cloud was formed in the sky, the day the first drop of rain fell on the surface of this earth, the day some sage tried to collect rainwater and diverted it to his farmlands, and the day mankind got an inkling of the immense value of water for the survival of life. Now once we look back, we see that starting from that very first day, the hydrology has come a long way, travelling through history and adopting many faces of knowledge. In the thematic framework, hydrology now has evolved to become a cross-cutting theme for civil engineering, agricultural engineering, earth science, environmental science, climatology, geography, geology, and watershed management. Hydrologic phenomena have proved to be the most intriguing among elements of our environment, that is, sun, soil, air, and water.

During the eighteenth century, there was a huge advancement in the field of hydrology, when new hydraulic principles and experiments such as Bernoulli's equation and Chezy's formula, and improved instruments such as current meter and tipping bucket rain gauge, were developed. John Dalton derived the principle for evaporation using lysimeter, and Mulvaney proposed the rational method for determining peak flood flow. Darcy derived his equation and developed his law of porous media flow, while Chamier applied rational method to the design of culverts, and Kuichling applied rational method for the estimation of storm water flows in urban areas.

In the nineteenth century, to meet the estimation and design demands of hydraulic engineering projects, empirical approach was used. However, at the start of the twentieth century, the quantitative hydrology was still undeveloped. The year from 1930 to 2000 is the period in which modern hydrology evolved through stages and developed as a geoscience. In this period, Horton developed infiltration theory, and Richard developed the equation for unsaturated flow. In the early 1930s, the main focus was rationalization of empirical results which were derived earlier and used in practice. In the middle of the period, theoretical basis replaced empiricism,

and government agencies started their own hydrologic research programs. During this time, the concept of hydrograph and more specifically the concept of unit hydrograph were developed. This was the first approach during which precipitation and runoff were used to check the rapid response of drainage basin.

In the period following that hydrology has been approached with a more theoretical basis than in the past, numerical models and digital computers were used to solve the hydraulic engineering projects.

2. Role of hydrological modeling

In the hydrologic system, a lot of changes have occurred in the recent past due to climate change, rapid urbanization, and industrialization. Climate change can significantly affect water resources by changing the hydrological cycle. The change in temperature and precipitation has direct effect on evapotranspiration, which directly affects the runoff generation. Some important indicators of climate change are droughts, floods, shifting seasons, melting of polar ice caps, changes in the pattern of oceanic currents, and lowering of water table [2]. In order to overcome these challenges, various hydrological models have been developed to investigate, understand, and explore solutions for sustainable water management. Hydrological models are basic and theoretical representations of the hydrologic cycle. They are mainly used for the prediction and understanding of hydrological processes. Hydrological models may be categorized as:

- a. models based on data collection
- b. models based on process description.

Models based on data are sometimes considered like black box systems. Shahid et al. [3] have illustrated the use of double mass curve in rainfall-discharge-sedimentation studies. Mathematical and statistical concepts are used in these models to link a certain input to the model output. Transfer function, system identification, regression, and neural network are commonly used techniques. Linear models are the simplest models. These models are known as stochastic hydrology models.

Models based on process description are more complicated than the stochastic hydrological models. Physical processes that occurred in the real world are represented through these models, such as representation of subsurface flow, channel flow, evapotranspiration, and surface runoff. Models based on process are known as deterministic hydrology models.

3. GIS applications in hydrological science

GIS is considered as one of the most important new technologies with the potential to revolutionize many aspects of society through increased ability to decisions and solve problems. GIS provides a digital representation of watershed characteristics used in hydrologic modeling. For very large areas, the main advantage of GIS is its ability to integrate, analyze, and manage large volume of data [4]. The applications of GIS in hydrology are mainly useful for watershed analysis such as surface and groundwater modeling, regional groundwater modeling, and water quality analysis. Hydrological models require huge volume of input data like soil cover data, topography, weather, and geologic data. The ability of GIS to integrate data from multiple sources such as boreholes and wells, subsurface isopach (or structure

contour) maps, and surface geology maps also allows data to be used simultaneously to develop a groundwater model. Water quality issues associated with regional changes in land use, such as urbanization and large-scale agriculture, can also be analyzed effectively using GIS. On a local scale, GIS can be useful for landfill siting and the selection of groundwater development and artificial recharge sites.

Remote sensing and GIS are integral to each other. Remote sensing is a technique to observe the earth's surface or the atmosphere from outer space using satellites (space-born) or from the air using aircrafts (airborne). Weather radar is used to determine speed and direction of wind, meteorology, climatology, and the study of ionosphere. Altimeters make use of remote sensing for measuring ocean currents, wavelength, their direction, and water level. Light detection and ranging (LIDAR) is used for vegetation sensing and for measurement of concentration of various chemicals in atmosphere and heights of different objects [5]. A number of major improvements have been made to existing hydrologic models, such as HEC-HMS, HEC-RAS, and EPA SWMM.

4. Role of artificial intelligence in hydrological science

During the last decades, mostly physical models were used for almost all hydrological investigations. These models give accurate results if detailed and accurate data are available; but in developing countries, accurate data are not available due to the financial and technical constraints, which results in model uncertainties and unsatisfactory performance. To overcome these shortcomings, artificial intelligence (AI)-based techniques have been recently used as alternative tools to traditional physical hydrological models [6]. Nowadays, artificial intelligence has been used in numerous hydrologic modeling such as rainfall prediction, rainfall-runoff modeling, evaporation estimation, flood forecasting, river stage prediction, sediment load modeling, and water quality simulation. Many techniques can be categorized under this newly available approach such as artificial neural networks (ANNs) and support vector machine (SVM). These techniques have become very popular and efficient for modeling complicated hydrological processes using relatively less cost, effort, and data. These approaches have proven to be highly efficient in solving the problems when the rules to solve such problems are difficult to be expressed which is the case in most hydrological processes. Therefore, AI techniques have become attractive alternatives to traditional physical modeling techniques for many hydrological applications. The position at the end of the twentieth century was that hydrology had developed to the state that it could be considered as a science whose analytical findings could be applied with profit to the solution of social problems.

5. Where we stand today?

Nevertheless, the most important lesson of this chapter is that observational hydrology is as old as human civilization. Second, our theoretical debts are to physicists, microbiologists, chemists, and mathematicians. Hydrologists used their hard-won observations to build complex water projects, but they did not create the important theories. Modern hydrology now emphasizes computer models over real example and illustrates important concepts with cartoons, while abundant real-world data are at our fingertips. In our view, future advancements of the hydrologic sciences will depend on a strong observational foundation consistent with its roots. This foundation enabled the large-scale water projects of ancient civilizations and is equally essential today.

The application of artificial intelligence, artificial neural networks, support vector machine, fuzzy logic, wavelets, entropy theory, network theory copula theory, chaos theory, and catastrophe theory are mostly in practice during the last two decades. With advances in data capturing, analysis, and transfer, it seems that the future of hydrology will be even brighter, with new tools at its disposal. Of course, computers have increased our ability to design systems, process data, and envision complex processes [7]. Hydrologic models will become so user-friendly that little hydrologic knowledge will be needed to operate them, just like one does not need to be an automobile engineer to drive a car or an electrical engineer to operate an electrical system. However, the models are simple or complicated, and these will be associated with a statement of uncertainty. Modern hydrology will play a great role to overcome the mega challenges of this century such as environmental security, water security, energy security, food security, water-food-energy nexus, health security, and sustainable development.

The water laws, water legislation, water apportionment, and water rights of various users and stakeholders leading to water conflicts, water wars, and conflict resolution mechanisms and strategies are the oldest as well as the latest trends in the hydrological sciences. Studies in transboundary aquifers and water bodies situated across the state and nation lines are the focus of research for many regional, national, and international; political and financial; bodies and forums. The physical, chemical, and medical health of such water bodies, their maintenance, and upkeep are the current issues of mutual cooperation as well as mutual conflicts. The spine of such mutual cooperation and mutual conflict resolution is the availability of database of water resources and their historical usages, giving rise to the importance of such neutral data repositories at national, regional, and international levels.

Education and awareness about the conservation and maintenance of water resources for all communities and stakeholders is another very important aspect of hydrological sciences. The advancement in today's modern technologies in the fields of electronics, computers, nanomaterials, medical, and energy, etc. has proven to be very fascinating and eye catching for the young brains. Hydrological sciences and the like have somehow gone on the backburners, getting not much attention. The old concept of "seven seas filled with water" needs to be reviewed by all with a concerted awareness and educational campaigns for saving and preserving this resource for the generations to come.

6. Conclusion

Hydrology, the science of water, is a multi-faceted science with branches like engineering hydrology, groundwater hydrology, surface hydrology, geohydrology, ecohydrology, hydrometeorology, hydroinformatics, statistical hydrology, and stochastic hydrology. Although the knowledge about science of water is available in abundance, which is spread all over in these disciplines, there is a need to harness the explorations of new vistas, latest developments, efficient frameworks, and cutting-edge technologies and collect these in one place, one volume, and one book so that all the experts, stakeholders, academia, and field professionals have a fair and free access.

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Author details

Muhammad Salik Javaid^{1*} and Laila Khalid²

¹ Civil Engineering Department, Abasyn University, Islamabad, Pakistan

² Capital University of Science and Technology, Islamabad, Pakistan

*Address all correspondence to: msalikj@abasynisb.edu.pk

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