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Analysis on Water Resources and Hydrologic Modeling

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ABSTRACT

As a brief history of watershed modelling, the current paper explores how hydrologic modelling How hydrologic modelling has evolved since the introduction of computers, as well as what the future holds. In hydrology, advancements can be traced back to improvements in data collection and processing as well as concepts and theories, as well as tools for computing and analysis. New information gathering and processing methods, as well as an increase in the usage of information technology tools, are projected to help hydrology become more integrated with both technical and non-technical sectors. This means hydrology will become increasingly important in the 21st century in dealing with concerns such as food and water safety and sustainability in the next decades. Groundwater contamination with metals and hydrocarbons, as well as the formation of suffocating sinkholes due to concentrated storm flow, does not justify the use of artificial recharge in urban areas. Water from minor dams built along the catchment headwaters can be channelled to metropolitan areas where it can be used as a supplement to the existing water supply. In agricultural and pastureland areas, soil percolation was expected to be particularly significant. Correct fertilising, maintenance, and irrigation procedures are deemed vital to reduce the risk of groundwater contamination and suffocating sinkhole development in these places.

1. INTRODUCTION

Many millennia have passed since the study of water's origins was first conducted (Biswas 1970). Mulvany (1850), Darcy (1856), and Fick (1858) all contributed to the development of hydrologic modelling, which can be traced back to this period. Experiments on flow-through sands led to the development of Darcy's law, which lay the groundwork for quantitative groundwater hydrology. Evaporation is proportional to the difference between the saturation vapour pressure of water and the actual vapour pressure in the air, according to Dalton's Law of Evaporation. Evaporation physics was able to progress thanks to this rule. Many revolutionary advances in hydrologic cycle modelling were accomplished over a span of more than a century until the 1960s. Mathematical physics, as well as laboratory and field experiments, contributed to some of these advancements. The pre-1960 developments in hydrologic research and engineering are largely responsible for where we are today in those fields of study. It was Chow's 1964 handbook of applied hydrology that documented improvements in hydrology until the 1960s, whereas Maidment and Hershey and Fairbridge'sencyclopaedia of hydrology and water resources dealt with advances that happened throughout the intervening years. There has been a long history of progress in hydrological cycle modelling, as described by Singh and Woolhiser (2002).

Overuse or underuse of water resources can be mitigated or avoided by effective management of water resources. Water resources management has relied on hydrologic models for decades. Predicting the effects of land use scenarios and evaluating management techniques are two common uses of simulation models (Greene et al. 1995). Using computers to plan and manage water resource systems is a growing subject of study in the last few decades.. Recent years have seen an increase in the use of geographic information systems (GIS), which allow researchers to provide high-quality, simply understandable results (Meyer et al. 1993; Schultz 1996). GIS tools have made substantial breakthroughs in hydrologic models that are physically based (Warwick et al. 1994). GIS can help experienced users organise, store, edit, analyse, and display local and attribute information about geographic data using spatial data management and analytic tools. In practise, however, GIS is rarely used as a platform for direct implementation of water system analytic methods (Djokic and Maidment 1993). Although mathematical models are critical in the field of water resources planning and management, they are not widely used in the field. It's obvious that GIS may profit from the geographical analysis and display capabilities of mathematical models, and the other way around (Shea et al. 1993; Olivera and Maidment 1999). Water resource management tools will be more effective if their individual capabilities are combined.

Hydrologic models such as JAMS J2000 are still rarely used in the region of Minas Gerais, despite their relevance. Groundwater resources and aquifer vulnerability, for example, can be determined by this modelling effort when aquifer protection is planned. Groundwater resources and aquifer vulnerabilities can also be assessed quickly and cheaply using hydrological processes' spatial distribution. It was therefore necessary to calibrate and evaluate a hydrological model in the Jequitiba River basin in Mins Gerais, Brazil, using the JAMS J2000 framework, and to interpret the results in terms of water resources management.TheJequitiba basin was chosen because the region's largest town (SeteLagoas) has been exploiting a karst aquifer since the 1980s, and there are obvious indicators of overexploitation in the aquifer (e.g., suffosional sinkholes).

2. MODEL REVIEW

A number of the most current hydrologic models are theoretically based and use lumped models like SWMM and STORM as well as HEC-1 and HSPF as well as the Sacremento and PSRM (Shamsi 1996). The use of these models in water resource management has been demonstrated to be successful. However, this type of model tends to overlook the importance of the catchment's spatial variability (Greene et al. 1995). Since they can account for the regional variation in watershed parameters, distributed hydrologic models have recently attracted a lot of attention. A few of the best-known physical distributed models include SHE, DROTEL, ANSWERS, and WATFLOOD (Abbott et al. 1986a,b; Shamsi 1996; Connolly et al. 1997). TOPMODEL was one of the first attempts to model dispersed hydrologic response using the principles of variable contributing area. Models like this one can geocode anything from the topography to the geography to the soil classification to land use. Simulation models, which divide the watershed into small sections called "grids," replicate the hydrologic processes inside each grid and the interactions among the grids using this data, precipitation data, and other meteorological information (Ewen et al. 1999). Two trends in the development of physically distributed models have arisen over the previous decade. For example, the SHE model is an example of a mechanism method, which relies on large-scale applications of the fundamental equations of mass and energy conservation. The other technique uses capacity-storage models. In this form of model, the average reaction of each cell is described, rather than the physics and variances that may occur inside the grid. One of these concepts is the tank-based distributed model based on the capacity-storage notion (Yoshino et al. 1990). Because of the uniformity of the terrain, soil hydrodynamics, and land features in this model, it may represent the entire basin. A catchment is depicted using a grid of square components. The model accurately depicts a wide range of environmental factors, including topography, soils, vegetation, geology, and channel networks. A predetermined time step is used to calculate it for each grid taking into account varying rainfall, temperature, wind speed and sunlight. There are two ways surface runoff can end up in a waterway: infiltration or entry via overland flow. This model includes a vertical discretion to account for water circulation through the soil profile.

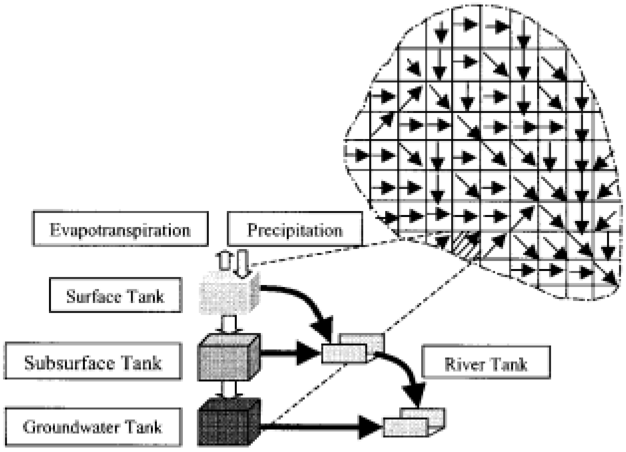


FIG. 1. The Runoff Formulation in a Symbolic Diagram

Figure 1 depicts a conceptual image of a watershed. For homogeneous conditions, a bigger unit size can be considered. The watershed is divided into square regions called "units," each with a square area of 1 km2. Soil hydrodynamic and land use characteristics are distinct characteristics for each block. In order to account for the transport of water from the surface to the aquifer, each block is divided into two or three levels. We take into account evaporative cooling, infiltration, surface and subsurface water movement, and groundwater flow. Infiltration happens when the interception volume, which is based on land usage and preceding conditions, is met during rainfall. Infiltration is a continuous process. The Darcy equation is used to calculate infiltration. Watershed outlets get extra rainfall once infiltration and evapotranspiration have been calculated. Overland and channel flow are both routed using the Manning equation-based kinematic wave method. An overland flow plane is represented by a specific slope and direction in each of the squares in the discretized watershed. It's the river tanks that gather the water from the overland and subterranean tanks as well as the groundwater tanks. Each tank is kept at a constant water level at all times (Sugawara et al. 1976). The PDTank tank model is referred to as the "basic" tank model in order to keep things simple and clear. One of the most comprehensive and accurate hydrologic modelling models on the market today. Finite-difference methods are used to solve the governing equations and represent the catchment features and input data in a grid square network. Because it has been thoroughly discussed elsewhere in the literature, only a general description will be given here (Yoshino et al. 1990; Suzuki et al. 1996; Abe et al. 1997)

3. HISTORY OF HYDROLOGIC DEVELOPMENTS

There have been so many advancements in hydrology since the 1850s that attempting to cover them all would be impossible. As a result, just a brief summary of some of the most significant developments will be offered. Topics, rather than dates, will be used to group these recent changes for convenient access.

Watershed geomorphology

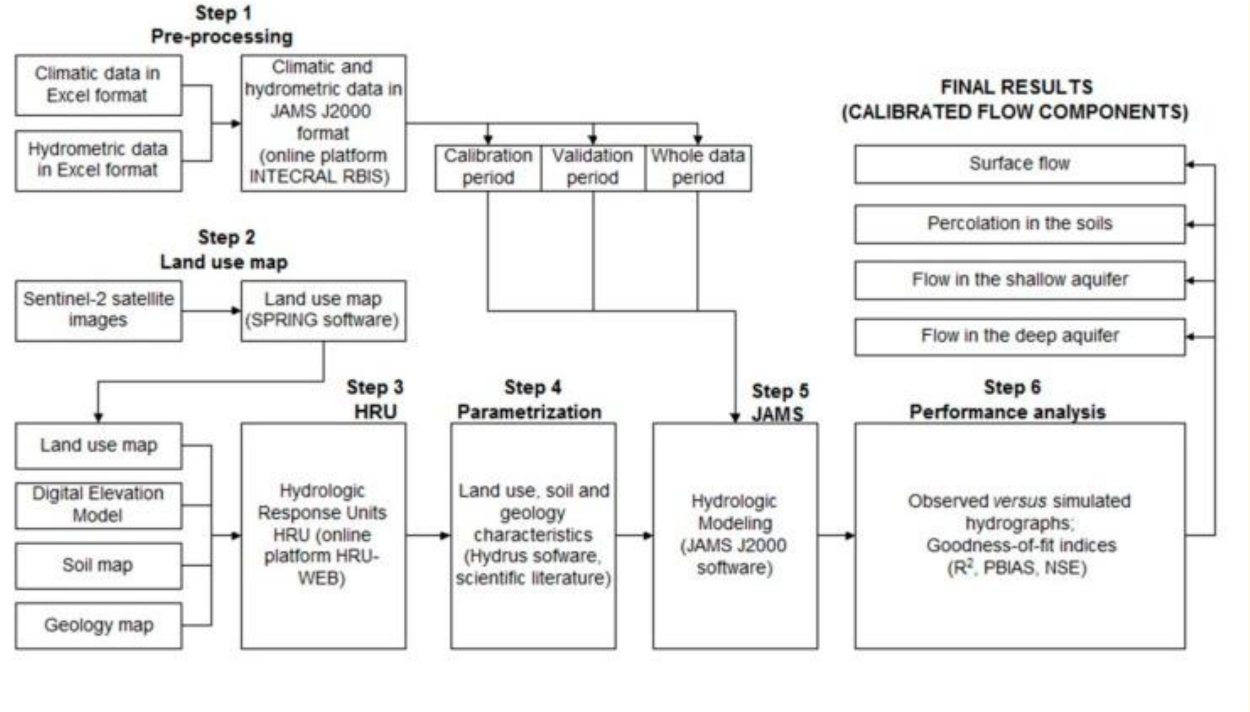
Quantitative geomorphology was founded on Horton's empirical rules, which were developed in 1945. Each stream has its own unique number and length of channels based on the law of stream slopes. Using this method, he came up with Horton ordering, a system for organising channels and basins. Additionally, Horton (1932) defined overland flow length and drainage density. He looked at how landforms and streamflows emerge when overland flow is the primary driving force. Horton–Strahler ordering is the name given to Strahler's modification of Horton's channel network ordering mechanism. Stream zones were first proposed by Schumm (1956). Mean annual discharge, as shown by Hack (1957), as well as Leopold, Miller, and Gray &Wigham (1956 and 1970, respectively), can be formulated as shown by Singh (1990). (1992). First proposed by Strahler (1957), Gray (1961) revealed that not all drainage basins were geometrically similar, despite the law of basin similarity. Gray (1961) discovered a correlation between drainage area and length, and further studies by Smart and Surkan followed suit (1967). Shreve (1966) established a statistical law of channel numbers, which Yang (1971) utilised to develop the law of average stream fall based on the idea of least energy dissipation. These pioneering initiatives have a considerable impact on the advancement of the next years. Fitzpatrick (2017) studied the geomorphology of a watershed and published his findings. From conservation principles and sediment transport laws, Smith (1974) calculated steady-state channel geometry. Entropy and the minimal energy dissipation rate theories are employed. Hydraulic geometries of the upstream and downstream sections were developed by Singh and Zhang (2008a, b). Beven and Kirkby (1993) and Baker et al. (1995) discuss channel network applications and flood geomorphology, respectively (1988). In 2001, Rodriguez-Iturbe and Rinaldo used fractal geometry to describe river basins. Geomorphology of the watershed has proven critical to the development of runoff prediction models for ungauged basins (Bloschl et al. 2013; Wagner et al. 2004).

Hydraulic geometry

Hydraulic geometry at a station and downstream includes the relationship between channel width, depth, velocity, roughness, and slope with discharge in both directions.. It is (Wolman 1955). In their study from 1953, Leopold and Maddock deduced hydraulic geometry relations of power form. As a result, a large body of literature has been produced that describes the derivation of these relationships using various theories, such as regime (Blench 1952), tractive force (Lane 1955), minimum entropy production theory (Leopold and Langbein 1962), stability theory (Stebbings 1963), and minimum variance theory (t) (Deng and Zhang 1964; Singh et al. 2003a, b; Singh and Zhang 2008a, b). Hydraulic geometry relationships in each theory produce distinct exponent values. This includes topics such as the validity and stability of power relations; channel patterns; stream size; exponents' dependency on climatic and environmental elements and land use; their extension to drainage basins; boundary conditions; and more. Singh also discusses these topics in further detail (2003).

4. HYDROLOGICAL MODELING

In the hydrologic modelling method, pre-processing of weather and streamflow data was the initial stage (Figure 2). For calibration (2003–2011), validation (2012–2016), and complete records for the entire time period (2003–2016), the data was gathered over the years 2003–2016 and included land use and occupation mapping, homogeneous hydrologic response units, input data parameterization, and JAMS J2000 framework hydrologic modelling. The study's 14-year time span was precisely established using the information that was at hand. A nine-year calibration phase was utilised, followed by a five-year validation period, before a performance analysis based on comparisons between observed and simulated hydrographs and goodness-of-fit indices was performed to assess the models' performance.



<u>Figure 2</u>Workflow used to perform the hydrologic modeling.

To organise the variables precipitation, temperature, humidity, hours of sunlight, wind speed and daily stream flow data in Excel spreadsheets in the first phase, The INTECRAL RBIS internet interface was used to convert the spreadsheets into JAMS J2000 files.

The second step was to clip the Sentinel-2 photos and check them for radiometric, geometric, and geographic consistency before using them to extract the research region. Clipped pictures were used to create a map of the area's land use, as well as its population. Also included were water features and natural vegetation as well as cultivated land, urban areas, and native vegetation (the Cerrado biome) in the classification.

When it came time to outline the homogeneous hydrologic response units, HRU-WEB was used (HRU). HRUs, which have similar pedological, lithological, geomorphological, topographical, and land use/land cover features, provide the basis of heterogeneous modelling entities. Their interconnection is provided by a topological routing architecture (see 63). It is possible to simulate the lateral water flow in the modelled watershed to achieve an explicit spatial discretization of hydrologic response The variety of karst caves cannot be taken into account while determining HRUs. In order to get the model and the observed stream flow to match, it is possible to calibrate the model.

In the fourth stage, lithologic, soil, and land use attributes were calculated or suggested using computer programmes, research articles, and technical studies. Table 1, Table 2 and Table 3 contain a complete list of all input parameters and their sources of information. In each geological unit, the upper and lower groundwater reservoirs were separated by a distance. Two runoff components are formed: one fast and one slow from the upper groundwater reservoir, and they are combined. Groundwater reservoirs are replenished by the soil's vertical discharge (percolation). Parameterizing groundwater reservoirs involves determining the maximum storage capacity of upper and lower reservoirs, as well as a retention coefficient for each (Table 3).

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Table 1**Land use and occupation parameters used in the hydrologic model.**

Land Use or Occupation	**Albedo (%)**	**Superficial Resistance (s/m)**	**Leaf Area Index (Dimensionless)**	**Effective Growth (m)**	**Root Depth (cm)**
Cultivated area	20.0	70.0	0.6	1.1	20.0
Urbanized area	16.4	70.0	0.01	0.0	0.0
Cerrado biome	14.2	70.0	0.8	20.0	120.0
Water bodies	4.0	70.0	0.0	0.0	0.0
Forest	15.0	70.0	0.9	30.0	300.0
Bare land	20.0	70.0	0.0	0.0	0.0
Reference(s)	[64,65]	[66]	[67]	[68]	[66]

Table 2soil parameters utilised in hydrologic model. There are practical measures to describe the pore size variations between water that can be stored against gravity (medium pore storage) and water that cannot (macro pore storage), respectively.

Soil Type	**Depth (cm)**	**Minimum Permeability Coefficient (mm/d)**	**Air Capacity (mm)**	**Field Capacity (mm)**
Red-yellow argisol	170	1	40	600
Haplic cambisols	230	1	37	1150
Red-yellow latossols	250	1	38	1500
TholicLitholic	50	1	13	125

Table 3Lithologic parameters used in the hydrologic model.

Lithologic Type	**Maximum Storage Capacity in the Upper Aquifer (mm)**	**Maximum Storage Capacity in the Lower Aquifer (mm)**	**Storage Coefficient in the Upper Groundwater Reservoir (d)**	**Storage Coefficient in the Lower Groundwater Reservoir (d)**
Orthogneiss	50	900	13	365
Clastic	50	800	16	365

Lithologic Type	Maximum Storage Capacity in the Upper Aquifer (mm)	Maximum Storage Capacity in the Lower Aquifer (mm)	Storage Coefficient in the Upper Groundwater Reservoir (d)	Storage Coefficient in the Lower Groundwater Reservoir (d)
sediments				
Limestone	70	1000	17	365
Silstone	60	900	14	365
Reference	[69]			

Finally, JAMS J2000's model initialization, rainfall estimations, soil water and groundwater, and stream flow routing modules were used to complete the process. We employed the NSIN II (Genetic Multi-Objective II) approach with a daily time step of 5000 iterations as the stopping rule [70] to calibrate and validate our results. There is a list of the modules in Appendix A.

step five involved comparing observed hydrographs to models, and assessing four goodness-of-fit metrics: a) the percentage of bias (PBIAS); b) the coefficient of determination (R2; C); c) the Nash–Sutcliffe (NSE) efficiency coefficient; and D) the natural logarithm of NSE coefficient (NSE) (LNSE).

CONCLUSION

Modeling hydrologic flow components, such as surface flow, percolation through soil, and groundwater movement, was done using hydrologic modelling. Compared to the rest of the country, surface flow in urban regions has increased fivefold. This is notable since the amount of surface water that is prevented from infiltrating (7.9 hm3 yr1) was expected. It was recommended that high-quality surface water be stored in wooded areas near the watershed headwaters using tiny dams rather than using storm water systems to artificially infiltrate this excess water because of the possibility of groundwater pollution from metals and hydrocarbons. Surface water storage capacity is calculated at 1.9 hm3 yr-1 in these sites. This surface water could be redirected and used in urban areas as a supplement to groundwater supplies within the framework of conjunctive water resources management. With conjunctive water resources management, the pumping rates and times at the drilled wells used to supply public water in SeteLagoas town can be lowered.

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