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Review Article

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A literature review of groundwater recharge in semi-arid areas

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Abstract The study of the risks of groundwater contamination is a major issue in the semi-arid regions. However, the role of the unsaturated zone is often overlooked in the assessment of groundwater recharge. In this paper, a literature review is presented to show the important role of the soil unsaturated zone in the process of groundwater recharge in semi-arid regions.

Keywords Groundwater recharge, Infiltration, Unsaturated zone, Semi-arid areas

Introduction

Groundwater is the major resource of water supply for about half of the countries. About 40% of the world's population uses groundwater and about 50% of the world's food production depends on irrigated agriculture in relation to pumping groundwater. In the 20th century, the water demand increased 6 times all over the world while population tripled; it is expected that this trend will continue into the next century [1]. Groundwater recharge in humid temperate and tropical climates typically accounts for more than 10% and in arid (dry-land) areas for less than 5% of the precipitation; in semi-arid and cold climates the values varies between these figures [2]. Globally, there are six approaches to determine groundwater recharge: bulk mass balance methods [3], methods based on outflow characteristics [4], mixing approaches [5], numerical and hydraulic [6], tracer methods [7], and mean-transit-time methods [8]. In general, groundwater recharge in humid temperate and tropical climates accounts for about 10% and in arid areas for less than 5% of the precipitation; in semi-arid and cold climates the values varies between these figures [9]. In this paper, a literature review is presented to show the important role of the soil unsaturated zone in the process of groundwater recharge in semi-arid regions.

Role of the Vadose Zone

The vadose zone extends from the topsoil to the groundwater surface. It is composed of three elements: the unsaturated zone, in which flow is governed by both capillary and gravitation, forces and in which most of the time capillary forces are dominant; the perched groundwater, which accumulates on very low hydraulic conductivity interfaces within the vadose zone; it is over- and underlain by an unsaturated zone; the capillary fringe on top of groundwater tables. Percolation is initiated by infiltration and directed by intrinsic parameters of the unsaturated soils; the parameters are the hydraulic functions, but also discontinuities of hydraulic conductivities in the unsaturated zone, which may both result from geologic, biotic and anthropogenic processes. As gravity, capillarity and intrinsic parameters modify the speed and direction of percolation, infiltration often exceeds groundwater recharge, because it is partially lost by ET or inter-flow [10]. The water balance in the vadose zone is triggered by infiltration and becomes modified by water storage and consumption. In this interaction, water storage close to the surface, within the effective root zone (from 0.5 m to 1 m). It can be described as:

$$\text{Infiltration (I)} = (\text{Transpiration (TP)} + \text{Evaporation (EP)}) + (\text{Specific groundwater run-off } (G_S) + \text{Specific inter-flow run-off } (G_I)) + \text{Soil water storage } (\Delta S)$$

In semi-arid and arid climates the soil water content varies between the water content at field capacity (θ_{fc}) and the water content at wilting point (θ_w) as:

$$G_S + G_I > TP + EP$$

$$\Delta S \geq I$$

$$\theta_w \leq \theta << \theta_{fc}$$

Groundwater Recharge under Semi-Arid Climate

Semi-arid areas are characterized by a rainfall of a value about 250 mm/year, but with a ratio of P/ET <0.5 [11]. Without the uneven distribution of precipitation the year around and the occasional heavy rainfall during the wet season [12], no excess water for either run-off or groundwater recharge would be available. Recharge is strongly correlated with the saturation deficit in the soil [13], it was established a threshold value of 140 mm of cumulative infiltration amounts that is necessary to make up for the moisture deficit in the soil incurred by the evapotranspiration during the rainless period. Under such conditions, recharge (and solute leeching) favors sites with a relatively thin soil layer. In valley terrains with deep soil and a rich vegetation cover, all of the soil moisture may be used up locally, except during an exceptionally rainy season [14]. This region, moreover, is characterized by large annual fluctuations as a result of the up to 50% variability of the precipitation amounts and their distribution during the rainy season, so that large fluctuations in the annual recharge are observed. The irrigation water input in these climate regions is another factor that needs to be considered in the water budget [15]. Conflicting effects of the irrigated agriculture come into play: On the one hand, the substitution of a rather dense plant cover for the sparse natural vegetation further decreases the P/ET ratio during the rainy season and potentially results in the accumulation of soil salinity, further acerbated by the irrigation’s water salinity [16]. On the other hand, the application of the irrigation water during the rainless period prevents the water deficiency in the soil during the dry period and enables a deep percolation already of the early rainfall [17]. Also, when applied in excess, the irrigation water may provide an additional percolation flux, alas accompanied by polluting chemicals [18].

In, the Mediterranean region is characterized by sandy and calcareous sediments, which have a relatively high infiltration capacity [19]. Some ponding in surface depressions or local overflow reservoirs may occur during strong intensity downpours, which exceed the infiltration capacity. This effect is accentuated in areas characterized by high clay content, in which case one encounters a large variability of the run-off/infiltration relationship, which makes the assessment of the recharge potential very difficult [20]. From a geo-chemical aspect, the dominant process is the increase in the salinity deposited by the precipitation and infiltration, because of the low P/ET ratio. In an extreme case, the increase of salinity is due to the precipitation of the less soluble layers of the soil water salinity. In these regions, practice of irrigated agriculture expresses itself in the concentration of the residual flux and more extreme changes of the chemical process of the groundwater recharge flux.

Conclusion

Groundwater recharge occurs in semi-arid areas most commonly through infiltration of surface run-off. Water percolation through the unsaturated zone is a main process of groundwater recharge. Hydraulic properties of the unsaturated layers are the major parameters involved in the water infiltration. An approach based on the properties will be a powerful tool to assess aquifer recharge and contamination in the semi-arid areas.

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