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Hydrologic Catchment Characteristics and Stream Character: A Brief Review

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Abstract: A catchment area (effective or topographic), which can be determined by the effective catchment index, is the area of land where precipitation is collected and flows into a general output (river, lake, wetland, bay, or other reservoirs); this area is very crucial in comprehensively understanding stream ecology. The physical processes that occur between rainfall on a catchment and runoff at the outlet are very complex and it is virtually impossible to give a full description of this part of the hydrologic cycle. Stream load, profile, gradient, rank among other characteristics of streams is a result of/ can be significantly affected by the catchment characteristics. This review will discuss the catchment characteristics that affect stream character/behavior and how. Understanding this offers a robust grasping of the connection between management activities and their consequences for stream ecosystem quality and freshwater availability.

Keywords: catchment area; stream; hydrology; morphology; ecosystem

1. Introduction

The catchment of a water body (hereby streams) is the area over which water, and hence diffuse pollutants, will travel both by overland (surface runoff) and subsurface movement (underground water) to enter the water body (Davies *et.al.*, 2007).[1] This area sometimes can also mean a drainage pool which includes all surface water from rainwater, snow blowers, hail, wet snow, and adjacent streams that run down to the common outlet, as well as groundwater beneath the Earth's surface. The drainage pools are connected to other drainage pools at lower altitudes according to a hierarchical pattern, with smaller drainage pools, which in turn merge into another common outlet Catchment is considered one of the major tools for successful understanding of stream ecology. The other fundamental determinants of the stream character are geology, climatic factors, and morphology but in cases where the catchment land cover is heavily modified, then catchment outwits geology and morphology in determining the stream character (Bird *et.al.*, 1990).[2]

The catchment area acts as a funnel, collecting all the water within the pool-covered area and guiding it to one point. Each drainage pool is separated topographically from the adjacent pools around the perimeter by a drainage divide (watershed divide) - a gap that constitutes a sequence of higher geographical features (such as a ridge, hill, or mountains) forming a barrier. Drainage pools may be similar but not identical to hydrological nodes, which are drainage areas outlined in such a way as to nest in a multi-level hierarchical drainage system as waters flow from high elevation to sea level, their potential energy is converted to other forms as they sculpt the landscape, developing complex channel networks and a variety of associated habitats (Kondolf, 1997).[3] The authenticity of stream processes, forms of energy and capacity are under continuous influence from the basin areas along the river length (Botkin & Keller, 1994).[4] This predominantly happens in alluvial streams which may even change the course or morphology due to natural or human forces (Biggs, et.al., 2004;[5] Peterjohn & Correll, 1984;[6] Vega *et.al.*, 1998;[7] Rashid & Romshoo, 2013[8] Isik *et.al.*, 2008).[9]

Geopolitical borders drainage basins are important for determining territorial borders, especially in regions where water trade was important and this alter catchment area in terms of activities happening at the catchment scale. The intensity of land use activities and the catchment size greatly influence the catchment impacts on the ecology of streams (Lintern, *et al.*, 2018).[10] The notable aspects of the catchment that affect stream character can be simplified as; basin morphology, climatic factors, vegetation, and land use, solid and drift geology, soils, and Man (Chow, 2010).[11] These can be related to the descriptive factors of a catchment as related to its hydrology by Horton 1932 (Boughton, 1968);[12] and this paper will review and discuss the influences of the above attributes to stream character.

2. Aspects of Catchment that Affect Stream Character

2.1. Man

This involves the anthropogenic activities happening at the catchment level that has significant effects on the character of a stream; majorly agriculture, deforestation, urbanization/industrialization, and damming.[9] Rivers and streams harbor many plant and animal species among other precious resources of freshwater. Despite their capacity for self-purification, the encroachment of human activities along the riparian land, basin area, and stream channel seems to alter this capacity, leading to the degradation of this important ecosystem.[8] The impact of these activities have dramatically altered the fluxes of growth-limiting nutrients from the landscape to receiving waters; stream discharge; direction and flow; transport and deposition; stream reproduction among other stream processes which have profound negative effects upon the quality of surface waters worldwide (Vogt, *et al*., 2015;[13] Hunter & Walton, 2008;[14] Anim *et.al*., 2018;[15] Rashid & Romshoo, 2013).[8]

River morphology is changing from its natural channel due to human activities, such as sand excavation from the bed, agricultural activity, disposal of municipal waste, and construction on the river (Safarina *et.al*., 2019).[16] Streams convey sediments from eroding uplands to depositional areas in the lower reaches. If the continuity of sediment transport is interrupted by dams or removal of sediment from the channel by gravel/sand mining, the flow may become sediment-starved (hungry water) and prone to erode the channel bed and banks, producing channel incision (downcutting), coarsening of bed material, and loss of spawning gravels for fish species that spawn on benthic material; since smaller gravels are transported without replacement from upstream (Kondolf, 1997).[3]

Regardless of the purposed functions of dams, which include water supply for residential, commercial, and agricultural uses; flood and/or debris control; and hydropower production, all dams trap sediment to some degree and most alter the flood peaks and seasonal distribution of flows, thereby profoundly changing the character and functioning of rivers (Kondolf, 1997;[3] Gao *et.al*., 2013;[17] Walling, 2006).[18] Downstream of the reservoir, encroachment of riparian vegetation into parts of the active channel may occur in response to a reduction in annual flood peak and sediment deposition especially in dams designed to curb flooding (March et.al., 2003;[19] Allan et.al, 1997;[20] Davies et.al, 2008;[21] Isik et.al, 2008;[9] Seeger, *et al*., 2004).[22]

Major changes in stream hydrology and morphology due to urbanization can be termed as the foremost stressors of urban streams (Wang et.al, 2001).[23] This can be used to explain why most streams draining urban areas exhibit ecosystem degradation (Doppelt, 1993).[24] Increased frequency of hydrologic and water quality disturbance, as well as channel geomorphology alteration, is experienced in urban streams when stormwater run-off through conventional drainage directly enters urban streams.[23] When these impacts are combined, they lead to poor ecological conditions of the urban streams referred to as 'urban stream syndrome' (Wang *et.al*, 2001;[23] Bird *et.al*, 1990;[2] Walsh et.al, 2012).[25] Urban streams are reported to have an increased level of connected imperviousness due to changes in channel morphology (enlargement, deepening, and simplification) as a result of changes in sediment supply and altered hydrology (Chow, 2010).[11]

Agricultural activities, as well as industrialization, increase exploitation of water resources as well as natural processes, such as precipitation inputs, erosion, and weathering of crustal materials, which degrade surface waters and damage their use for drinking, recreational, and other purposes.[23,18]

Pollution from agriculture is recognized as one of the drivers of change having a significant negative impact on water quality and aquatic biota.[1] The pollutants may include nutrients and other chemicals used to maximize production in agricultural riparian lands, animal waste or animal health bi-products as well as sediment resulting from eroded soils. They affect the character of the stream by both altering the physicochemical characteristics and quality of the stream through increment in eutrophication activities of the stream, changes to sediment composition/deposition, and by direct toxicity impacts on the organisms within it.[1] The complexity in nature and diverse sources and pathways into the stream makes it difficult to manage and control these pollutants.

Vast forest areas being converted to agriculture, settlement and pastures cause degradation because of overgrazing by the cattle, increased runoff, and reduced allochthonous sources of energy to streams and rivers (Botkin & Keller, 1994).[4] Population density also exerts an important influence on nutrient concentrations in river systems through waste disposal, both domestic, manure, and livestock wastes (Brown *et.al*., 2005).[26] Deforestation and denudation of drainage basins hydrologically impact streams by reducing the rate of groundwater recharge and increasing storm water runoff into streams (Herlihy *et.al*., 1998).[27]

Another human entanglement that may affect the character of a stream though indirectly is the management activities that may be purposed to control and manage water-related resources. This may happen locally or internationally in cases of geopolitical borders where two or more countries/states share a drainage basin. Bioregional political organizations are formed including agreements between states (e.g. international treaties and/or interstate treaties) or other political entities in a specific drainage basin to manage the body or reservoirs into which it flows. Laws or policies may be formulated to dictate for example how many human activities should be practiced in the drainage basin. Activities such as sand/gravel mining, grazing, deforestation, damming, and fishing may be included in the clauses and due implementations done hence affecting the stream load, nutrient intake, and run-off (Lambert, 2006).[28]

2.2. Basin Morphology

Parameters of basin morphology such as slope, shape, and size have a great role in determining various aspects of a stream. Safarina *et.al.,* 2019[16] discussed that all the above parameters of catchment morphology directly affect river slope, flow depth, flow velocity, river border, and that also land cover affects river capacity or discharge. Calculation of the velocity of flow in channels gives slope and hydraulic radius -the ratio of the area of flow to the wetted perimeter.[12] This determines the morphological purpose of a stream that include flowing of water from one point (highland areas) to another point (near sea level- lower reaches) and with it transporting the nutrients, suspended & dissolved solid materials then utilizing or depositing them downstream as the river loses its energy at various stages of the channel (Karbassi *et.al*., 2008).[29]

Basin morphology often goes hand in hand with the geology of the catchment and can sometimes be determined as one of the most significant factors determining the number or probability of flooding. The characteristic topography, shape, size, type of soil and land use (paved or roofing areas) all play a role in this. The topography and shape of a watershed determine the time it takes to reach the rain, and the size of the catchment area, soil type, and development determine the amount of water to reach the river. Topography, as a rule, topography plays a big role in how quickly the runoff reaches the river. Rains falling in steep mountainous areas will reach the primary river in the drainage basin faster than flat or slightly slim areas. The shape of the catchment also contributes to the speed at which the drain reaches the river.

Topographic characteristics of catchments and drainage basins are better defined than most other types, mainly because of the high accuracy, and low cost with which they can be evaluated. Many topographic characteristics can be measured or evaluated from maps in the comfort of an office and have the advantage of being clear to define and measure. Measurements can be replicated with ease and this permits precise definitions to be made.

These topographic characteristics of catchments can be used to determine stream character by dividing the stream features into Lineal characteristics which are defined by Stream order, Bifurcation ratio, Stream length, Mean stream segment length, Mean stream length, Stream length ratio, Length to center of catchment, Average length of overland flow, Inter-basin length of overland flow, Average width of catchment, and Maximum basin length; Areal characteristics expressed as Catchment area, Mean catchment area of stream segments, and Area ratio; Drainage characteristics described as the Drainage density and Stream frequency or stream density; Shape characteristics and Slope characteristics outlined in form of Mean Stream segment slope, Slope ratio of stream segments, Mean stream slope and texture ratio; Elevation Characteristics circumscribed as Relief, Maximum relief, Maximum basin relief, Relief ratio, Mean elevation, Rise and Hypsometric curve; Orientation characteristics classified as stream Orientation and Exposure; Channel Characteristics and Surface Characteristics like Percentage of surface impervious and Percentage of surface as open water.[12] All the above morphological physiognomies actively and directly define and determine stream character with its constituents.

2.3. Land Cover

Natural or altered land covers in the catchment levels of streams play major ecological roles of the streams in terms of nutrient (organic matter-leaf litter), chemical (erosion), and metal addition; and directly affects the runoff into streams as well as underground water recharge. The land cover comes to inform of bare rock, barren land, forest cover, cropland, degraded forest, grassland, orchards, perennial snow, plantation, scrub, and wetland (Llorens et.al., 1997;[30] Doppelt, 1993;[24] Jordan et.al, 1997;[31] Yadav & Rajesh, 2011).[32]

Vegetation characteristics like Abundance population density, percentage composition, leaf spread and percentage cover of shrubs and grass alters storm water runoff by reducing the surface movement of this water and consequently increasing groundwater sippage.[25] This alters the equilibrium between underground water and runoff which may result in the reduced carrying capacity of a stream. The absence of these otherwise is an ecological disaster since it leads to excess storm water runoff filling upstreams to superfluous limits causing flooding (Davies *et al*., 2007).[1] The exhaustive search suggests the importance of land cover metrics on in-stream water quality, with land cover metrics having high weights of evidence for all constituents of vegetation.

2.4. Geology

Catchment geology comprises of the soil and rock types and it depicts stream size in terms of depth, width, and length (Biggs *et.al*., 2004).[5] The composition of the catchment soils will determine the amounts of erosion by storm runoff along with which all kinds of pollutants will be carried into streams. More erosion alters the sediment capacity of streams and in alluvial rivers, this affects channel erosion through downcutting as the larger sediments erode the river channel (Davies *et.al*., 2008).[21] Reduced streamflow and increased sediment discharge are also major impacts of streams due to the geology of the catchments. There can be a great deal of variation in infiltration capacity and moisture storage capacity within a single soil type. The texture, structure, porosity, availability of minerals/metals (like Si, Ca & P), and conductivity of the soils in the catchment all determine the chemical composition of streams as well as sediment discharge and mineral composition of these streams (Seeger, *et al*., 2004).[22]

The type of soil will help determine how much water reaches the river. Drainage from the drainage zone depends on the type of soil. Some types of soils, such as sandy soils, are very freely drainage, and precipitation on sandy soil is likely to be absorbed by the earth (Boughton, 1968).[12] However, soils containing clay can be almost impenetrable, and therefore precipitation on clay soils will escape and contribute to the volume of the flood. After prolonged precipitation, even freely drainage soils can become saturated, which means that any further precipitation will reach the river, and not be absorbed by the earth. If the surface is impermeable, precipitation will create a surface out of the course, leading to a higher risk of flooding; if the earth is permeable, precipitation will penetrate the ground (Lintern, *et al*., 2018).[10]

2.5. Climatic Factors

Climatic aspects of the catchment areas of streams like rainfall patterns, drought, or floods precisely define stream character, especially the hydraulic and hydrologic characters. This actively explains the ecological differences in considerable observations and aptitudes in rivers and streams from arid areas, flood plains, and rain forests. The physical processes that occur between rainfall on a catchment and runoff at the outlet are very complex and sometimes it is almost impossible to give a full description of this part of the hydrologic cycle (Boughton, 1968).[12] Precipitation patterns in the lines of flushing regimes may change due to climatic aspects of the catchment and this justifies the robust variability in the nutrient cycling process among other evolutionary stream processes in different climatic periods.

3. Conclusions

Land use practices in the stream catchments have tremendous ecological and socioeconomic importance and they depict the way we are treating our freshwater ecosystems which in turn alter the characters of these streams. Land-use changes considered of great impact in altering the hydrologic system of streams are mainly driven by the rapid socio-economic development like in the case of conversion of cropland to an urban area due to urbanization, as well as changes within classes such as a change of crops or crop rotations. Wagner (2013)[33] emphasizes that when these changes occur in places with low stream discharge, it could result in an increase in water scarcity and thus contributes to a deterioration of living conditions.

Catchment morphology, land use, geology, climatology, land cover among other hydrologic characteristics of catchments cannot be underestimated on how their relative effects play a role in determining stream character like Stream order, gradient, discharge, load, productivity among others.

In a snapshot, the longitudinal connection and bank to bank relationships of streams explain in bulk the stream ecology and the interaction of stream and its channel, discharge, carrying capacity, energy inflow & losses among others are critical in providing insight to stream character. This brief review provides perception on how catchment, with all that it stands for, contributes to determining stream character.

Conflicts of Interest

The authors declare no conflict of interest.

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