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## IMPORTANCE OF GEOLOGY AND GEOMORPHOLOGY IN WATERSHED HEALTH ASSESSMENT

### SUMMARY

Watersheds constituted by different geology, geomorphology, climates, land uses, soils, ecological communities, and vegetation covers. The watershed landscapes have established over geologic time while being shaped by patterns of climate, vegetation, and lithology. However, understanding the nexus between watershed health, geology and geomorphology has been less considered and requires a deep knowledge of their spatiotemporal scales of evolution. The current article, therefore, attempts to provide a brief review of geology and geomorphology concepts, importance and applications in watershed health assessment. Additionally, a list of most important geologic and geomorphologic criteria for watershed management and assessment provided as well. The provided information provides useful insights for land managers and decision makers and thus helps in the identification of gaps in knowledge that need to be addressed on a priority basis. It is highly suggested that the future developments in watershed health studies have focused in the direction of the geological and geomorphological process, taking advantage of empirical observations, mathematical and conceptual modeling to attain a quantitative description of real watershed health conditions.

**Keywords:** health; geomorphic insights; geomorphic system; landform; land management

### INTRODUCTION

Geology includes elements such as lithology and structural settings (Wilson and Droste, 2000). Whereas, geomorphology processes incorporate the climate or hydrology sectors with parent materials, sediment, and vegetation cover to form a landform (Swanson et al., 2017). Geomorphology indeed comprises both quantitative and qualitative explanations of landscapes and landforms, as well as processes investigations and process interactions creating these forms in temporal and spatial scales (Renschler and Harbor, 2002). Geology and geomorphology sectors are fundamental elements in watershed landscape analysis (e.g., García-aguirre et al., 2014; Jain et al., 2012) due to their influence on terrain evaluation and life of existing plants and animal species. Physical processes and their linkages with ecosystem quality have become a

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priority within the context of watershed health (EPA, 2012) and one of the aspects that need to be considered in the monitoring and ecological health assessment.

The global increasing focus on the geological and geomorphological processes has highlighted their importance in watershed sustaining (Ahn and Kim, 2017a and b; EPA, 2014; 2013; 2012; 2011; Jat et al., 2008). For example, morphological characteristics of the river channel, floodplain, and valley sides and consequently the river biocoenoses arrangement along the river continuum determined by geomorphic processes functioning in particular river reaches (Rinaldi et al., 2013). Indeed, since the 1990s, increasing scientific studies have carried out concerning watershed health assessment. A progressive evolution toward process-based watersheds restoration has occurred (Hazbavi et al., 2018a and b), where the target is to restore natural geomorphic processes (Rinaldi et al., 2013). Thence, the essential need to consider process-oriented approaches and self-restoration strategies, persistently (Rinaldi et al., 2013; Wohl et al., 2005).

Increasing attention is being paid to the ecosystem health assessment and management on a watershed basis, necessitating a cross-disciplinary approach to data collection and analysis. Linking the geologic and geomorphologic data with the watershed health assessment applications can provide a simpler and more accurate way to understand the complex behavior of watersheds. Therefore, this review was made to highlight this important issue and giving new insights for developments of future watershed health assessment frameworks.

## **METHODS OF GEOLOGY AND GEOMORPHOLOGY VARIABLES MEASUREMENT**

### **Field surveying**

The main method to study geologic and geomorphologic data is field surveying. Indeed, fieldwork is the formative experience central, and the U.S. Geological Survey (USGS) is well suited to guide the upcoming workforce (Gundersen et al., 2011). Cianfrani et al. (2005) applied a rapid geomorphic assessment (RGA) following the Vermont Department of Conservation Protocols (VTDEC, 2002). This method characterizes the channel geomorphology based on the field data. Expect six conditions to identify viz., pre-modified, constructed, degradation, threshold, aggradation, and restabilization (For more information see Cianfrani et al. (2005); VTDEC (2002)). However, there are many methods to help the derivation of valuable and useful information as explained below.

### **Air photo and digital techniques application**

Air photo interpretation and digital techniques including GIS-based spatial analysis and modeling, and remote sensing provide high important information on the geologic origin and structure (Field, 2015; García-aguirre et al., 2014). The sandstone, shale and limestone rocks can be distinguished easily with help of remote-sensed documents interpretation. The geomorphology knowledge is an essential tool to recognize landform types, the strike and dip attitudes, the orientation of highlights and shadows drainage patterns, and the relative

susceptibility degree of the formations to flooding and other natural hazards (García-aguirre et al., 2014; Verstappen, 1988).

Watershed health researches provide ample evidence that morphological characteristic can exert a significant influence on the processes shaping other landscape patterns. Digital elevation models (DEM) is one of the important remote-sensed documents and as an elementary data used for watershed health assessment. DEM could be extracted from contour map through ArcGIS spatial analysis tool and based on two maps of slope and aspect (Kabite and Gessesse, 2018; Field, 2015; Ding et al., 2008). Simultaneous analysis of maps of non-biotic elements viz. geology, geomorphology, and biotic elements include land use/cover allow to generate synthetic and systematic information of watershed landscape in the form of the bio-geomorphic land unit (BGU) maps (Zonneveld, 1995) applicable for watershed health assessment.

It is further necessary to mention that the different geomorphological indices developed based on digital techniques to better understand the behavior of geologic and geomorphologic changes and process. The stream-gradient index, hypsometric integral, valley floor width–valley height ratio, drainage basin shape, drainage basin asymmetry, and mountain-front sinuosity are some examples of the applicable indices for geologic and geomorphologic characterization (Faghih et al., 2015).

### **Connectivity analysis**

Geomorphic connectivity in a watershed landscape affected by different Landforms or human disturbances (Poepl et al., 2018; 2017). In regards to the significant importance of connectivity to analyze the bio-physical fluxes movement in a large geomorphic system (Jain et al., 2012) introduced as an important determinant for watershed health assessment (Hazbavi et al., 2018b and EPA, 2012). Connectivity can be measured through flux interaction(s) (functional connectivity) and physical connectedness (structural connectivity) between Landforms (Jain et al., 2012). Geomorphological variables determine the potential for water and sediment to be transported through a geomorphic system (Keesstra et al., 2018). In addition, the connectivity could be investigated from three dimensions of longitudinal, lateral and vertical through geomorphic systems. In fact, geomorphic systems with low connectivity are less sensitive and thus more resilient to disturbances (Poepl et al., 2017). Understanding the reaction of the watersheds against to drivers the concept of connectivity thinking could be adapted as a useful approach in watershed health assessments.

### **Other Methods**

Rădoane et al. (2015) noted that for the geomorphologic characterization of the river beds in the established moments of time there is a morphometric database regarding the features of the entire alluvial lowland of the river, at the active stripe of flood-plain, at the stream channel itself. Strahler (1957) quantified the geomorphic methods in two general classes of (1) linear scale measurements and (2) dimensionless properties. The criteria measured by each method is described in Table 1.

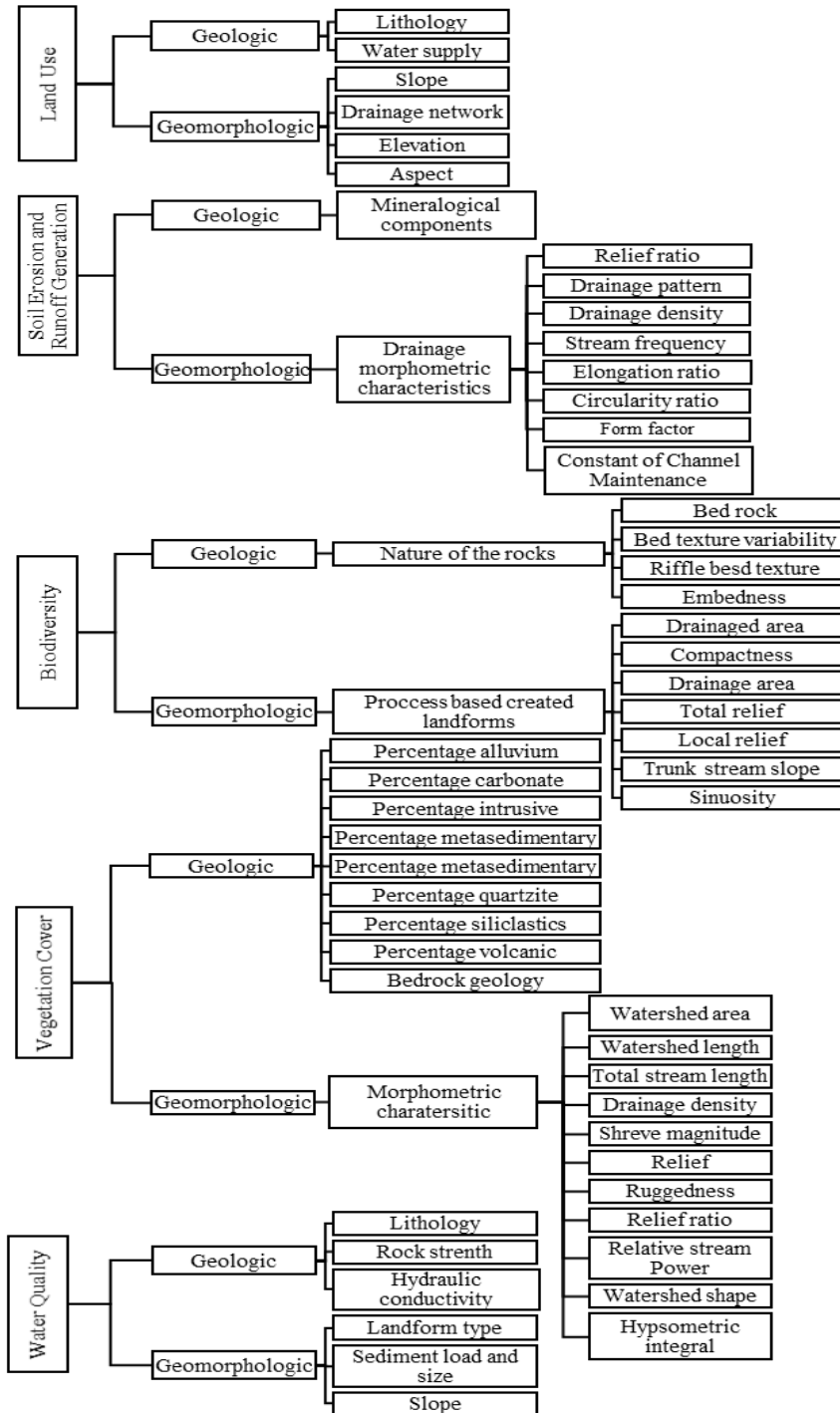


Figure 1: Geological and geomorphological criteria and interrelationship with other affecting criteria in watershed health assessment

Table 1. Quantitative methods of watershed geomorphology (Adapted from Strahler, 1957)

Linear Scale Measurements	Dimensionless Properties Measurements
<ul style="list-style-type: none"> <li>• length of stream channels of given order</li> <li>• drainage density</li> <li>• constant of channel maintenance</li> <li>• basin perimeter</li> <li>• relief</li> </ul>	<ul style="list-style-type: none"> <li>• stream order numbers</li> <li>• stream length and bifurcation ratios</li> <li>• junction angles</li> <li>• maximum valley-side slopes</li> <li>• mean slopes of watershed surfaces</li> <li>• channel gradients</li> <li>• relief ratios</li> <li>• hypsometric curve properties and integrals</li> </ul>

The U.S. Geological Survey (USGS) also provides digital and nationwide information through a publicly accessible data server for many parts of the world ([www.usgs.gov](http://www.usgs.gov)). Recently, GEOMORSIS, a semi-automatic geo-morphometric analysis package is released for quantitative analysis of watershed geomorphology using GIS. It has six basic modules i.e., AUDRALA, STMPARA, RELEIF PARAMETER, REPORT GENERATION and BASGEO. Win Basin is another watershed analysis system applicable for extraction of realistic drainage networks and calculation of geomorphological indices from DEMs. The Natural Resources Conservation Services (NRCS) Geo-Hydro as an Arc GIS application extension could compute geomorphological and hydrological elements (Khan et al., 2016).

After a very extensive literature review, the most important of geologic and geomorphologic criteria was then extracted and summarized in Figure 1.

### **WATERSHED HEALTH ASSESSMENT, GEOLOGY, AND GEOMORPHOLOGY RELATIONSHIP**

Watershed health assessment and restoration have been undertaken using a wide variety of approaches and techniques (Hazbavi et al., 2018; Sadeghi et al., 2018; Liao et al., 2018; Hazbavi and Sadeghi, 2017; Sadeghi and Hazbavi, 2017; Li et al., 2013; An et al., 2002) yet there is often a high rate of failure to improve watershed ecosystems health. Part of the problem is allocated to a failure to understand the fundamental principles of watershed-scale geology and geomorphology that control watershed responses to disturbance (Townsend, 2009). Notwithstanding the increasing experiences and evolving approaches in the field watershed health assessment, very limited researches have considered the geology and geomorphology sectors for the ecosystem (even include watershed) health assessment as given in Table 2.

Recently, Hazbavi (2018) provided a list of watershed health assessment tools as follows: 1) Thermodynamic analysis, 2) Network analysis, 3) Multi-metric approach, 4) Predictive model approach, 5) Healthy watersheds initiative (EPA Protocol), 6) Reliability-resilience-vulnerability (RRV), 7) Vitality (Vigor)-organization force-recovery force (VOR) and 8) Pressure-state-response (PSR) and its new versions.

Table 2. List of geological and geomorphological criteria used in watershed health assessment

<b>Criteria</b>	<b>Reference</b>
Stream order, stream length, drainage density, drainage texture Area, perimeter, length and width of watershed	Jat et al. (2008)
Water storage (aquifer storage capacity vs. unused capacity) Water storage (aquifer storage filled with “clean” water vs. contaminated water) Net recharge/withdrawals (water year) Detention/retention basin capacity vs. bio-retention capacity Extent and diversity of soft bottom conditions in rivers and streams. Water flow dynamics adequate to support diverse habitats (e.g., volume, rate, and seasonality). Sediment and material flows adequate to support diverse habitats. Per capital water use Local (native) vs. imported source for delivered	Vos et al. (2008) and Antos et al. (2011)
Drainage area, compactness, drainage density, total relief, local relief, trunk stream slope, map slope, erosion index	Walters et al. (2009)
Bedrock and surficial, soil resistance properties, geography - continental, mountain, valley, and coastal Landforms, geomorphic reaches, functional process zones, active river areas, ground water- dependent, springs, seeps, wetlands, lakes; Historical planform and floodplain modification, channel, floodplain, and valley geomorphology, sediment, and woody regimes; Geomorphic stability and stage of channel evolution, channel geometry and hydraulics, distribution and sorting of sediment and wood, boundary conditions and vegetation (soil erodibility testing, roughness elements and coefficients)	EPA (2011)
Percent of assessed stream miles in reference condition	EPA (2012)
Dominant Surface Geology	EPA (2013)
Stream habitat condition, rating and dam presence/absence	EPA (2014)
Substrate, habitat complexity, velocity/depth regimes, bank stability, channel alteration	Wu et al. (2015)
Ratio of stream length of reference condition in watershed to total stream length in watershed	Ahn and Kim (2017a)
Percentage of assessed stream length in the reference condition	Ahn and Kim (2017b)

Table 3. SWOT analysis of geology and geomorphology concepts in watershed health assessment (Adapted from Downs and Booth, 2011)

<b>Strengths (S)</b>	<ul style="list-style-type: none"> <li>- Directly concerned with the surface of the earth</li> <li>- Directly concerned with regional (e.g. watershed) functions that are the basis for maintaining healthy ecosystems and valued native biological populations</li> <li>- Long history of studying the role of human impact in system functioning</li> <li>- Well positioned to integrate biology, engineering and planning into practical solutions</li> <li>- Well positioned to practice design and management with nature to achieve truly sustainable designs</li> </ul>
<b>Weaknesses (W)</b>	<ul style="list-style-type: none"> <li>- Poor representation at policy levels</li> <li>- Poor representation on funding bodies to ensure adequate research funds Lack of standard methods</li> <li>- Lack of routine monitoring of geomorphic systems</li> <li>- Viewed as a sub-set of engineering, especially in more quiescent landscapes</li> <li>- Lack of a professional group and professional accreditation</li> </ul>
<b>Opportunities (O)</b>	<ul style="list-style-type: none"> <li>- Directly concerned with the surface of the earth</li> <li>- Directly concerned with regional (e.g. catchment) functions that are the basis for maintaining healthy ecosystems and valued native biological populations</li> <li>- Long history of studying the role of human impact in system functioning</li> <li>- Well positioned to integrate biology, engineering and planning into practical solutions</li> <li>- Well positioned to practice design and management with nature to achieve truly sustainable designs</li> </ul>
<b>Threats (T)</b>	<ul style="list-style-type: none"> <li>- Geomorphology practiced by others with little or insufficient training, and so lacking in broad areas of necessary skills</li> <li>- Perception of simplistic geomorphological descriptions of system functioning that do not apply in all cases</li> </ul>

According to the widely used procedure for watershed health assessment i.e., United States Environmental Protection Agency (EPA, 2012), six essential indicators of (1) the landscape condition, (2) geomorphology, (3) hydrology, (4) water quality, (5) habitat, and (6) biological condition are fundamental to the assessment of watershed health. It is understood from the literature that the geology and geomorphology play a critical role in upland function (Stringham and Repp 2010) as it dictates soil and vegetation characteristics found within the watershed system (Hecker, 2017). However, the watershed geomorphology (e.g., valley type) could not be altered by the human, but the land management decisions could influence the stream morphology and etc. (Hecker, 2017). As a result of human-induced infrastructure, the terrestrial and aquatic habitat fragmented throughout a watershed and could affect the natural stream geomorphology, significantly (EPA, 2012).

Towards above-mentioned notes, the geomorphological application in watershed health assessment like environmental management as stated by Downs and Booth (2011) could be analyzed by prospects of strengths, weaknesses, opportunities, and threats (SWOT) as explained in Table 3.

### CONCLUSIONS

Interdisciplinary research is still needed in the areas of geology and geomorphology to appropriately implement watershed assessment and monitoring procedures within the scope of the watershed health. Watersheds should be considered as basic landscape units for understanding natural resources and environmental issues. This review has focused on issues surrounding the geologic and geomorphologic application to watershed problem-solving. Despite applied geomorphology long but largely unrepresented history within the watershed health discipline, escalating environmental awareness and better technical expertise have brought increased opportunities to contribute to integrated watershed management. Linking the geologic and geomorphologic characteristics with the health concept of the watershed can provide a scientific basis and more accurate and simpler way to apply effective and fruitful strategies to identify particular areas within the watershed that should receive a higher priority for management. In addition, it needs to learn more about related terminologies to geology and geomorphology concepts like hydro-geomorphologic, eco-geomorphologic, geochemistry and other similar ones and obtain more comprehensive information. It does not forget to give more attention to know more about the nexus of geological and geomorphological sectors with other like ecology, hydrology, climate and etc.

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