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Significance of Chronic Headwater Stream Impairments in Water Resource Management: A Southern California Case Study

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Abstract

Sources of water resource impairments are well known, however, less attention has centered on the role of headwater streams in supporting water resource management objectives. This study quantified the extent to which human-environmental factors contributed to the physicochemical characteristics of two headwater tributaries that contribute to a percolation basin and downstream surface flows to the Santa Ana River Basin, Southern California. In situ sampling for stream temperature (˚C), stream flow (m/s), nitrate (NO3-), ammonium (NH4+), turbidity (NTU), dissolved oxygen (DO), conductivity, and pH with lab assessments for E. Coli (EC), total coliform (TC) and total dissolved solids (TDS) occurred during drought and seasonal precipitation conditions. Multiple parameters exceeded regulatory standards simultaneously, including NO3- (85-96%), NH4+(49-69%), TDS (78-90%) and TC (32-62%) during dry and wet conditions, suggesting consistent impacts to water resources entering the percolation basin [2]. Multivariate analysis indicates higher concentrations of NO3- and DO during storm flow events, excessive concentrations of TC, TDS and elevated conductivity levels during drought, base flows conditions and the presence of sewer systems also influence the variability of TC and NO3- [3]. Results suggest the frequent (>monthly) monitoring and quantification of headwater stream quality prior to entering percolation basins is vital to developing comprehensive, sustainable water resource management strategies.

Keywords: Headwater streams; Resource management; Seasonal physicochemical trends; Semi-arid regions; Surface water quality; Sustainability; Resiliency

Introduction

Landscape-hydrological relationships: The role of headwater streams

The protection of water resources is of paramount concern as the nexus between a growing global human population and related landscape changes coupled with climatic uncertainty continues to adversely impact water quality and quantity [4]. Alterations to the natural landscape are often driven by human activities including crop and livestock production, industrial discharges, failing septic (i.e. non-point, diffused input source) and sewer systems (i.e. sanitary system), and increases in impervious surfaces (i.e. houses, roads, and parking lots). Although efforts to mitigate water resource impairments and promote water security are ongoing, the World Health Organization (WHO) and the Center for Disease Control (CDC) estimates that 1.8 billion people (25% of the global population) are without access to adequate sanitary water and 1 in 3 people do not have access to safe drinking water, magnifying the need for collaborative, comprehensive and sustainable resource management strategies (CDC 2019; WHO 2020) [5]. To develop such strategies, it is important to examine the spatial context and extent to which specific land types, activities, infrastructure and climatic conditions influence the physicochemical characteristics of water resources throughout the hydrologic network. Extensive literature highlights surface water impairments: however, this is primarily in the context of longitudinal surface water segments within a watershed or catchment. Unfortunately, headwater streams are also subjected to a variety of short and long term anthropocentric impacts, including dams, urbanization, agriculture, mining and forestry as observed in the central and Southern Appalachian region (USA) [6]. Despite being recognized as an important hydrological feature, headwater streams are often excluded in water resource management plans, as evident in the European Union Water Framework Directive, because headwaters are often not considered “bodies of surface waters” (BSW). This exclusion presents considerable limitations to surface water and watershed management. For example, poor soil management and excessive application of fertilizers on landscapes draining to and along headwater streams cause significant impacts to downstream users, including increases in operational costs for water treatment facilities and reductions in water quantity for irrigation as documented in Indian, Illinois and Iowa as well as other states [7]. In the past few decades water resource management must consider the anthropocentric and ecological implications of extreme shifts in climatic patterns, including severe droughts and intense, but short-lived, precipitation events. Drought conditions can complicate management objectives by minimizing or eliminating surface and subsurface flows and retention, lowering water tables and causing land subsidence and habitat loss.

Stressors are primarily related to excessive groundwater withdrawals, that have doubled globally since 1960, used for agricultural irrigation, and industrial and municipal (i.e. residential, commercial) uses that are further diminished by increasing and spatial expansive prolonged drought conditions (WRI 2020) (Figure 1).

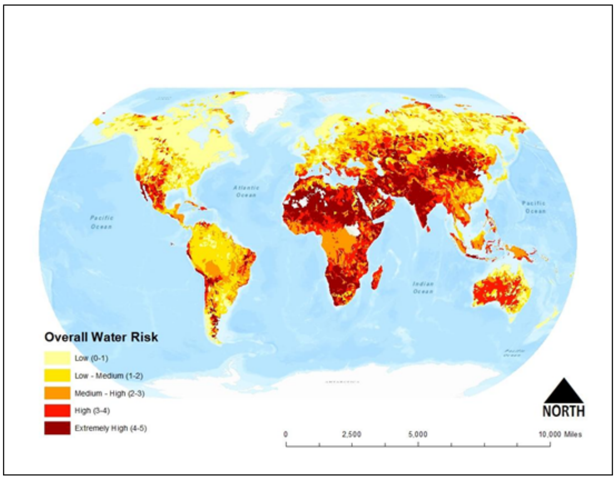

Figure 1: Overall water risk of each country around the world.

The southwestern region of the United States, which has climatic conditions (i.e. arid to semi- arid) and landscapes similar to those found in other high water stress countries located in Europe, South America, Africa, the Middle East and Asia, is facing extremely high (>80%) water stress. In the United States, headwater streams account for 53% of total stream miles which represents a significant portion of surface water resources [8]. However, only 19 percent of all surface waters in the US have been assessed, indicating that far less is known about headwater stream quality. The need to prioritize and quantify our understanding of the extent to which human-environmental factors influence the physicochemical characteristics of headwaters streams is magnified when one considers that across the US alone, 604.000 kilometers of streams provide water for public drinking water resources with 333.000 kilometers (i.e. 58%) of these surface waters coming from headwater streams (EPA 2019a).

Results and Discussion

Catchment landscape characteristics

Previous studies highlight the need to understand landscape features and their associations with various water quality impairments. In this study, barren land represented a majority of the land use types across all three catchments primarily related to steep slopes that are devoid of vegetation and catchment 3 (i.e. WC3) had the highest percentage of impervious surfaces (i.e. 31%) largely associated with roads and buildings, followed by catchment 1 (i.e. WC1) (i.e. 18%). In contrast, catchment 2 had the lowest percentage of impervious surfaces and the highest percentage of evergreen forests (i.e. 39%), indicating landscape variability across the three catchments

Drought conditions resulted in stream base flows across all three sampling sites with WC3 having no surface flows from June 26 to November 28. The first precipitation event occurred on November 30 (0.43cm) which was followed by more significant rainfall on January 14 (3.94cm), 21 (1.24cm) and February 3 (2.38cm) and 11 (1.6cm) [9]. Also observed was that consistently higher stream flow rates occurred days and even weeks after rainfall across all three sites.

Quantifying headwater stream physicochemical characteristics

Descriptive statistics highlight relevant physicochemical characteristics including high variability among parameters and sampling locations as well as multiple parameter means exceeding regulatory standards [10]. Distinguishing observations include the high variability (i.e. variance) of total coliform (TC), E. Coli (EC), conductivity and total dissolved solids (TDS) and means that exceed regulatory standards at all three sampling locations for NO_3^- (9.8 mg/L, WC1; 8.4 mg/L, WC2; 10.6 mg/L, WC3), NH_4^+ (0.81 mg/L, WC1; 1.1 mg/L, WC2; 1.1 mg/L, WC3) and TDS (192 mg/L, WC1; 187 mg/L, WC2; 228 mg/L, WC3). In contrast, mean TC only exceeds recommendations at WC1 (1389 cfu/100mL) and WC2 (1068 cfu/100mL) and conductivity at WC3 (340 µ S/cm). Trends for nutrients (NO_3^- , NH_4^+) reveal that NO_3^- consistently exceeds regulatory standards (94%, WC1; 84%, WC2; 95%, WC3), however, NH_4^+ only exceeds regulatory standards 48 percent (WC1), 54 percent (WC2), and 68 percent (WC3) during the study period. Other trends in impairments include TDS, which exceeded objectives 90 percent (WC1), 78 percent (WC2), and 84 percent (WC3) across all sampling events and conductivity exceedances were highest at WC1 (62%) when compared to other sites (46%, WC2; 32%, WC3).

Physicochemical parameter correlations

Physiochemical correlations centers on stream flow, stream temperature, and concentrations of nutrients (NO_3^- , NH_4^+), coliforms (TC, EC) and TDS because of the highly variable climatic conditions (i.e. drought vs. precipitation conditions) that directly influence stream flows, and these parameters have the highest percent of samples exceeding federal, state and regional standards across all sampling sites. Sites WC1 and WC2 displayed similarities in relation to stream flow including positive correlation with DO (r=0.74, p<0.01; r=0.58, p<0.01) and NO3- (r=0.52, p<0.01; r=0.54, p<0.01), suggesting that elevated flow rates (i.e. wet periods) are associated with higher levels of DO and concentrations of NO3-.

Headwater streams provide an opportunity to spatially isolate these relationships within the hydrologic network so that BMPs can target impairments specific to each catchment to further minimize downstream impacts. It should also be noted that although there are inverse relationships among many of the parameters, it does not dismiss previous findings that even in these cases, many of these parameters are exceeding regulatory standards and objectives

Regression model relationships

Regression models were developed to determine the extent to which independent variables influence a given dependent variable with findings further evolving the identification of specific factors impacting headwater stream quality. As previously noted, conductivity, TC and TDS were highly variable across each of the sampling sites during the study period. Although the R2 values associated with these regression models were relatively weak (R2=0.32, 0.31 and 0.23 respectively). The R2 value indicates that the wet season, stream flow (m/s), and the number of sewer systems in the drainage area account for 54 percent of the variability in NO3- across the study site. The first variable to enter the regression model is the wet season, suggesting that during the wet season, NO3- concentrations are 212 percent higher when compared to the dry season.

Human-environmental influences on chronic headwater stream impairments

Extreme shifts in climatic conditions (i.e. drought vs. precipitation) coupled with landscape characteristics are highly influential on the physicochemical characteristics of headwater stream quality leading to chronic impairments year round, especially as it relates to NO3-, NH4+, TDS and TC concentrations. In addition to quantifying the annual frequency in impairments, resource agencies should quantify, spatio-temporally longitudinally and across the hydrologic network, the extent to which parameters are exceeding regulatory standards simultaneously. This knowledge may support and ensure that hydrologically comprehensive strategies and policies are effective in the short and long term. Precipitation conditions illustrated similar patterns to drought conditions in relation to TDS with 94 percent and 77 percent of samples exceeding regulatory standards at WC1 and WC2 respectively. Nutrients are also of concern across the entire study site and are of increasing concern in surface and groundwater resources globally. Potential anthropogenic point and nonpoint sources of nutrients include animal waste and plant and animal decomposition, as well as effluent from wastewater systems. As a result, it is an advantage to the planning process to elevate the importance of headwater streams by including these hydrological features to ensure the protection and security of water resources globally.

Conclusion

Documenting the climatic impacts on the physicochemical characteristics of surface water quality in headwater streams is necessary to determine the extent to which headwater streams may be influencing water resources throughout the entire hydrologic network. This study illustrated drastic changes within headwater streams related to landscape features and climatic conditions by identifying the significance of nutrients, harmful bacteria and TDS entering a percolation basin during both drought and precipitation events. Dismissal of headwater streams in watershed planning and water resource management limits knowledge about how upstream factors are spatially contributing to stream impairments that threaten water quality and quantity downstream and across the hydrological network. Monitoring and assessment strategies implemented in this study can be applied globally to further expand knowledge and to underscore the importance of including headwater streams in assessments. This inclusion supports sustainable resource management strategies that are hydrologically comprehensive. In doing so resource agencies and communities will be able to meet the ever changing socio-economic needs and unpredictable weather patterns, especially droughts that reduce both water quality and quantity.

References

1. Alexander RB, Boyer EW, Smith RA, Schwarz GE, Moore RB (2007) The role of headwater streams in downstream water quality. J Am Water Resour Assoc 43: 41-59.
2. Alford JB, Debbage KG, Mallin MA, Liu Z (2016) Surface water quality and landscape gradients in the north carolina cape fear river basin. The Key Role of Fecal Coliform. Southeastern Geographer 56: 428-453.
3. Alho C, Reis R, Aquino P (2015) Amazonian freshwater habitats experiencing environmental and socioeconomic threats affecting subsistence fisheries. Ambio 44: 412-425.
4. Arnold CL, Gibbons CJ (1996) Impervious surface coverage: The emergence of a key environmental indicator. J AM PLANN ASSOC 62: 243-258.
5. Barakat A, Baghdadia ME, Raisa J, Aghezzafb B, Slassib M (2016) Assessment of spatial and seasonal water quality variation of oum Er Rbia river (Morocco) using multivariate statistical techniques. Soil Water Conserv Res 4: 284-292.
6. Bouwer H (2002) Artificial recharge of groundwater: hydrogeology and engineering. Hydrogeol J 10: 121-142.
7. Burkholder J (2007) Impact of waste from concentrated animal feeding operations on water quality. Environ Health Perspect 115: 308-313.
8. Cahoon LB, Hales JC, Carey ES, Loucaides S, Rowland KR, et al. (2006) Shellfishing closures in southwest brunswick county, north carolina: Septic tanks vs. storm-water runoff as fecal coliform sources. J Coast Res 22: 319-327.
9. California Drought Monitor (CADM) 2020 California Drought Monitor Map.
10. California State Water Board (WB) 2002 Stream Temperature Indices, Thresholds, and Standards Used to Protect COHO Salmon Habitat: A Review.