IDENTIFYING SPATIAL SCALE AND INFORMATION BASE: AN ESSENTIAL STEP FOR WATERSHED MANAGEMENT AND PLANNING

Shova Shrestha, PhD

1 BACKGROUND

All human, plant and animal life and interactions and physical processes are connected through river basins/watersheds. A river basin or watershed describes an area of land that contains a common set of streams and rivers that all drain into a single larger body of water, such as a larger river. Rainwater that falls subsequently drains into the watershed. Not only does water run into the streams and rivers from the surface of a watershed, but water also filters through the soil, and some of this water eventually drains into the same streams and rivers.

Nepal is drained by four major rives systems namely, Koshi in the east, Gandaki in the middle, Karnali in the west and Mahakali in the far west. Rivers and streams of these four major systems are grouped into three different categories based on their origin (Bogati et al., 1997). Rivers originating from High Himalaya region is categorized as Class I rivers. Rivers originating from high and middle mountains (Mahabharat range), most of which are tributaries of Class I rivers are categorized as Class II rivers. Class III rivers originate from Siwaliks and either flow into Class I and II rivers or flows directly into southern Gangatic Plain. These rivers and streams flowing through different physiographic regions constitute number of river basins and watersheds of varying sizes and characteristics. Mountain watersheds are characterized by high physical diversity and relatively high population densities with nearly all the people relying on watershed-based resources for their livelihoods. Watershed ecology is thus very important to the people of this country. Sharp physiographic and climatic contrasts in combination with other natural phenomena contribute to the fragility of Nepalese watersheds.

Basin and Watersheds form natural boundary and they do not follow political / administrative boundaries, and in fact encompass several cultural, regional and economic boundaries. What happens in one part of the watershed will impact resources and people who depend on it in the area downstream. Rational management of upstream and downstream of a watershed is equally important for the sustenance of the environment. Therefore it is extremely important to use an integrated spatial approach for managing watersheds and river basins. With the concept of multidisciplinary integrated approach got an impetus the integrated approach of GIS and Remote Sensing is being recognized universally as the unique, highly effective and versatile technology for planning, management, monitoring and evaluation of natural resources and environment (Ma, 2004). Because of the highly complex nature of human and natural systems, the ability to understand them and project future conditions using a watershed approach has increasingly taken a geographic dimension. With the advancement of earth science technologies, software environments, computers and availability of large volumes of digital data, GIS application in watershed management has changed from operational support to prescriptive modeling and tactical or strategic decision support system (Tim & Mallavaram, 2003).

2 GIS AND WATERSHED PLANNING

Many real-world spatially related problems, including river-basin planning and management, give rise to geographical information system based decision making. Data and information which are the basis for river basin management decisions are directly or indirectly linked with the geographical location, with the spatial entity. For this reason, geographical information systems (GIS) can play an important role in this process, since GIS is providing a convenient environment in spatial decision problem domain (Prah et. al. 2013). GIS has an advantage of assembling, developing, storing and analyzing vast amount of data from different source and in different format. Since watershed vary in size and characteristics and watershed planning need to deal with different types of data, GIS is a very useful tool to analyse and visualize relationship of the elements within watershed and how those elements interact. The establishment of linkage between various types of processes such as relationship between the hydrological processes, soil erosion and vegetation cover, human activities in current climate change and vulnerability context is very possible through GIS and other integrating tools. Some of the common application of GIS in watershed management planning includes:

- Delineation and identification of spatial scales of watersheds
- Inventory preparation of resources within watershed
- Assessment of available water and land resources
- Characterization and prioritization of watersheds for planning, feasibility studies
- Topographical analysis by extracting layers like slope, aspect, drainage density
- Thematic Mapping of resources and socio-economic aspects
- Action Plan maps for land and water resources development by integrating information

These applications are carried out during different steps of watershed planning process as outlined below:

Step 1: Inventory (Information base) and Resource mapping which includes existing status of resources, trend mapping mostly, temporal change between past and existing condition such as landuse and management practices. Most frequently used GIS data layers during this step included soils maps, land use maps and topographic data, climatic information, hydrologic information including streams, rivers, and lakes, as well as infrastructures such as roads and other information to facilitate orientation.

Step 2 & 3: During step 2 and 3 of watershed planning process topographical and other analysis will be carried out based on inventory prepared during step 1. Characterization and prioritization of watersheds and identification of problem/critical areas or high potential risk areas within a watershed is very important during this stage. Characterization and prioritization using GIS allows the relatively limited human and physical resources to be focused on the critical areas. Based on identified problem areas and issues, vision/ goals and strategies for plan could be developed.

Step 4: GIS during this step is very much useful as visualization tool for watershed management plans. GIS application is mostly confined to thematic mapping. Map output includes existing resources, socio-economic aspects such as population density, disadvantaged group cluster areas, intervention areas, conservation areas, buffer zones could be developed as supporting document.

Step 5: GIS is utilized for performance mapping after certain time period of implementation under monitoring and evaluation activities. Application could include mapping of change in status of resources, quality, quantity and access etc. after plan implementation.

3 CHALLENGES OF USING GIS

With the technological advancement and access to digital spatial database, GIS is becoming useful tool for integrated sector like watershed management and planning. But also associated with application of GIS are the challenges. GIS is a data dependent system. Unless there is up to date data, database inventory, standard methodologies and institutional mechanism GIS will not itself serve for informed and enhanced decision making. Imperative is also institutional aspects of GIS implementation. Some of the major challenges at the institutional levels are: familiarity with the tools, integration of watershed concept into GIS and integration of GIS into watershed planning process. Watershed planning and management process includes (i) technical (data, knowledge and technology) and (ii) social and ecological aspects which needs to be integrated into the process. Watershed planning and management is also an iterative process requiring an interactive process. A major challenge is facilitating the effective linkages among technical, social and ecological components through GIS. A framework is essential which highlights the institutional setting, partnerships and information technology. These three components should work synergistically to form the building blocks for GIS based watershed management planning. GIS for watershed comprises structured database of geospatial and temporal water, land and other resource data combined with tools for information processing to support watershed inventory, analysis, modeling and decision making. As GIS integrates vast amount of data from different sources and methods for analysis, development of basic methodological framework is required for watershed management planning. GIS process for watershed management planning involves data collection, database development, analysis and information and data production for decision making and management purpose. On the other hand, application of GIS tool for watershed management should be ascribed at three different stages, namely:

Making data GIS friendly is the first and foremost process. As stated earlier, GIS is a data dependent system which requires certain standard formats for data input. This process involves activities like: i) review existing data: a) collection of existing data from secondary sources b) collection of data from the field (ii) finding out mismatches and verification with reference data (iii) editing, refinement and updating data for further use and (iv) standardization and creating finalized data layers for the project area. After these processes, output will be created in the form of Information Base which includes: (i) final reference data (Watershed data at different spatial scale), (ii) updated watershed Boundary with codes (iii) updated river network data (iv) updated resource data

Use of tool for different type of spatial analysis and modeling can be carried out only after standardized database development. Use of GIS tool may range from basic map preparation to more advanced and complex spatial analysis and modeling integrating different data.

The third step though not directly related to watershed planning process is the evaluation of effectiveness of tools used. So that improvements needed, suggestions and recommendation of such tools could be done for future use.

4 DIGITAL WATERSHED BOUNDARY DATA AND CODING

The first step in any planning exercise is to identify the area the plan is to address (Meltz, 2008). But when planning for a watershed, the boundary is not as self evident as it is for administrative area such as city or district planning. Finer details of hydrological units for implementation of various watershed management schemes at lowest possible spatial scale is increasing with the community based participatory planning process in water sector. The importance of digital watershed boundaries at different spatial scale is also important due to limitation of resources such as skilled human resource, time, and cost for delineation and unavailability standard/consistent watershed boundaries at different spatial scale. This is also vital for visualizing and understanding the upstream and downstream relationships throughout a river basin at different scales. As the scale of the watershed changes from micro catchment to a larger river basin, the nature of the linkages and related effects varies. The effect which occurs at one scale (micro catchment) might have a different magnitude and impacts on another level (river basins). For the proper planning and implementation of any development program on watershed basis, it is essential to have watershed in the form of digital/hardcopy maps along with their relevant attributes. GIS as a tool has made it possible and there is increasing application of GIS tool and techniques for watershed level data creation and analysis.

The advent of GIS tools and technology, and availability of different resolution digital elevation models (DEMs) have resulted in the evolution of procedures to automatically map or derive channel networks and watershed boundaries. Due to the developments on these, much of the information that we gather from the topographic maps can now be gathered electronically using GIS (Shrestha & Miyazaki, 2006). Watersheds are not always easy to distinguish and define. Though watershed of a small stream (e.g. first order stream) is discrete and relatively easy to identify, watershed of large river is complex and difficult to define because it comprises number of smaller watersheds and catchments. There is also the matter of scale to consider.

5 REVIEW OF PRACTICES OF WATERSHED BOUNDARY DELINEATION AND CODIFICATION SYSTEM

Scale plays a critical role in preparation of effective management plan. Planning at too large scale is mostly a reason for failure of many plans because of more generalized planning objectives and clustering of sub watersheds with different characteristics into one management plan. Besides, it should consider increased number of stakeholders and varying interests, increased number of political/administrative units and generalized recommendations (Meltz, 2008). Range of standards and coding system have been developed in different countries (for example EPA and USGS in USA, Central groundwater Authority in India, Danube River System in Europe, Mekong River Basin in South east Asia etc) in an effort to understand, identify, catalogue, and name watersheds at different spatial scale. Digital spatial layers of watershed boundaries facilitate spatial analysis at different scale and nesting of lower level information into higher level data. Similarly, the codes facilitate simple hierarchical aggregation and querying using only the tables without using GIS files (e.g. shapefiles) of the stream network and watershed datasets (Furst & Horhan, 2009).

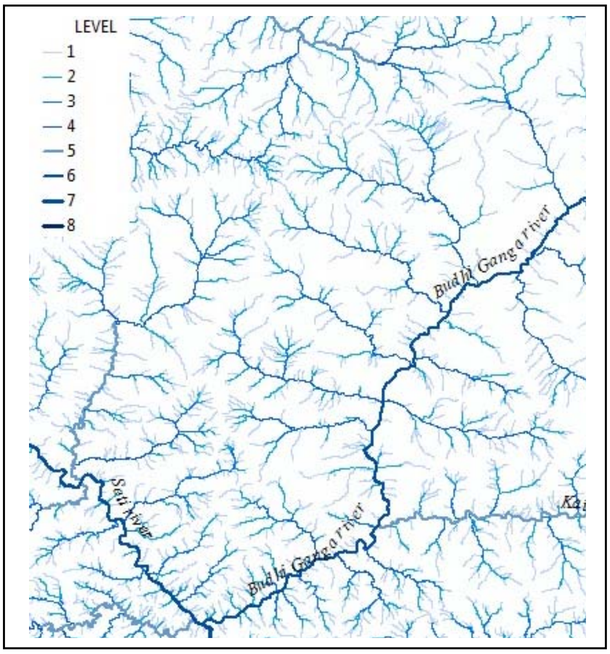
In order to standardize and catalogue watersheds in the USA, a hierarchy of Hydrologic Units was first the developed in 1974 by USGS (USGS, 2015). Each hydrological unit was assigned a code number based on where in the hierarchy the watershed belonged for very broad planning efforts. In the early 1990's, with GIS technology delineation of small scales watersheds and sub watersheds (under States responsibility) for large areas is carried out by Federal Geographic Data Committee (FGDC). The underlying concept is a topographically defined set of drainage areas organized in a nested hierarchy by size. Lowest Planning unit identified is of 25.9 sq. km. and appropriate management area unit identified is 5.18 km2. Similarly, in India, Watershed Atlas has been developed by Central Ground Water Board for entire country which includes digital boundary, name and codes for each spatial level of watersheds. It has developed a system for delineating and codifying the water region from larger areas into smaller hydrologic units i.e. sub watersheds following the 4 stage delineation which serves a national level framework of watersheds. Development of watershed oriented coding systems in Europe began more than 30 years ago and since then many different kinds of system depending on the natural conditions have been developed in various European countries (Brilly, 2010). Danube river basin system has been categorized into three levels for trans-boundary integration. Similarly, Mekong river basin has been categorized into 4 different levels for trans-boundary integrated analysis. Besides, national level sub-divisions of watersheds of each country both in case of Danube and Mekong river basin are also emphasized.

6 DISCUSSION

Need for delineation and coding of watershed boundary using GIS

Delineation of functional sub-watersheds of sizes ranging between 15-50 sq. km. within a district into a certain number and prioritization based on land use, land system and population density was initiated during 1990s in Nepal for sub-watershed level management and planning maps (Bogati et. al. 1997). However, sub-watershed prioritization is manually performed using topographical, landuse and landcover. The use of digital geospatial data for the purpose of river basin management is tightly connected with the quality and connectivity of data. The quality of spatial data is considered in accordance with certain standards that involve positional and attribute accuracy, logical consistency, completeness etc., but also in the wider context such as functional connectivity, semantic accuracy and usage (Prah et. al. 2013).

A systematic delineation of river basins for the whole country at institutional level is not yet attempted in Nepal and project area based delineation of river basin is more prevalent. Those have served the immediate project purpose but the attempts made so far for delineation of watershed units has some limitations as different data sources and methods have been employed. Previously, watersheds were delineated manually using 1:50,000 topographical sheets. It was followed by using 1:25,000 scale topographical maps with 20 meter contour interval. More recently, automated watershed boundary delineation is becoming common using GIS tool and data sources such as 20 meter digital topographical data sets, digital DEMs such as SRTM, ASTER and other high resolution satellite imageries (DSCWM, 2016; IWMI, 2012; Shrestha & Miyazaki, 2006; WECS, 2006). Though most of the organizations use similar data sources, number and boundary shape of sub-basins and watersheds derived from those vary widely (for example DSCWM identified 42 watersheds whereas IWMI identified 33). It is realized that there is a need for systematic delineation of the river system and watershed boundaries at a national scale for a suitable spatial working scale which will aid to systematic and standard spatial units to be utilized for planning, management and development of surface water resources of the country. Keeping in view the growing requirement of watershed boundary at different spatial scale for implementing diverse development activities for different departments/ agencies for various purposes, the current need is to provide platform and base map adopting a simplified and easily



understandable approach as well as coding system which will serve as a tool for assessment, planning and implementation of water resources at various spatial scales.

The thorough review of watershed boundary data and coding system of different countries provide basis for watershed boundary derivation and coding at different spatial scale for Nepal. Evaluation of prevalent watershed boundary delineation process and data used for it by different organizations in Nepal, it is realized that common standard baseline is requisite. In this context, use of river network digital topographical data set at scale 1:100, 000 produced by Survey Department of Nepal at district level could be the baseline for either contour based or DEM based watershed delineation. This database provides standard river names for main rivers, stream order (based on Strahler's classification, 1957) and reference basin number (figure 1). As required, subsequent lower order sub-watershed and catchment boundaries could be delineated nesting into standard watershed created using the baseline data.

7 CONCLUSION

A watershed cannot be delineated without knowing the river and streams it is based on and using only contour/DEM. So the first step to making data GIS friendly for watershed management is to identify river/stream and its tributaries and delineate watershed boundary. Though, GIS technology and available data has advanced to the point where watersheds for any area can be delineated by agencies, organizations, or individuals at a level of precision, it does not replace but augments the need for a standardized system of watershed boundary delineation, use of standardized spatial data and cataloging. This also facilitates identification of gaps and providing base for more detailed boundaries where required.

Importance of finding reliable GIS methodologies for identifying and visualizing watershed characteristics at different scales is unambiguous. This is especially important for watershed boundary delineation where a small local change may have a dramatic impact on planning and management efforts. The current issues related to GIS data source and watershed boundary delineation are i) same data source but variable definition and variable watershed boundaries, ii) no or variable coding for the same watershed and iii) irregular feature boundary representation of watershed boundary due to raster to vector conversion in case of automated watershed generation. Thus immediate solution to such issues are use of standardized data source e.g. topographical digital data set with existing contour/DEM data and development of standard coding system which will reinforce creation and use of standard spatial scales and codes for watersheds of the country.

Reference:

Bogati R, Kharel B. P. and Shrestha B. D. (1997). *Guidelines and Methodology for Sub-watershed Prioritization in Watershed Management Planning. Department of Soil Conservation*, Ministry of Forest and Soil Conservation. Nepal.

Brilly M.(2010). *Danube River Basin Coding*. Hydrological Processes of the Danube River Basin. pp 125-14.

Furst J. and Horhan T. (2009). *Coding of Sub Basin and river hierarchy to support GIS-based hydrological analyses at different scale*. Computers & Geosciences. Volume 35, Issue 3, Pp 688–696.

G. Pegram, Y. Li, T. Le. Quesne, R. Speed, J. Li, and F. Shen. 2013. *River basin planning: Principles, procedures and approaches for strategic basin planning*. Paris, UNESCO.

IWMI, (2012. *Climate Change and Vulnerability Mapping in Watersheds in Middle and High Mountains of Nepal. Building Climate Resilience of Watersheds in Mountain Eco-Regions, ADB/TA, Department of Soil Conservation and Watershed Management (DSCWM)*, Government of Nepal.

Ma. Y. (2004). *GIS application in Sub Basin management. Nature and Science, 2 (2).*

Meltz, D.(2008a) *Sub Basin Planning and GIS: The influence of geographic information systems on the Watershed planning process*. A research paper, submitted to Department of Geography and Planning, University at Albany, SUNY.

Prah, K. Lisec A. and Lisec A. (2013). *Digital spatial data as support for River basin management: The case of Solta river basin. SPATIUM: International Review. No. 29*, pp. 59-67.

Shrestha, M.B. and Miyazaki, T.(2006). *GIS Application on Drainage Network Extraction. Disaster Mitigation of Debris Flows, Slope Failures and*

Landslides. Universal Academy Press, Inc. / Tokyo, Japan. pp. 803–813.

Simonovic, S. P., Kundzewicz, Z. W. and Rosbjerg, D. (1995), *Modelling and Management of Sustainable Basin-scale Water Resource Systems*. Proceedings of a Boulder Symposium, July 1995. 1AH5 Publ. no. 231.

Sipe, N. G. and Dale, D. (2003). *Challenges in using geographic information systems (GIS) to understand and control malaria in Indonesia*. Malaria Journal.Vol 2. No 36.

Tim U. S. and Mallavaram S. (2003). *Application of GIS Technology in Watershed-based Management and Decision Making*. Watershed Update. Vol. 1, No. 5.

Tiwari, K. R., Bajracharya, R.M. and Sitaula, B.K, (2008). *Natural resource and Sub Basin management in South Asia: a comparative evaluation with special references to Nepal*. The Journal of Agriculture and Environment. Vol. 9, June.

USGS, (2015). *Hydrologic Unit - Water Resources of the United States*. United States Geological Survey. Washington.

Author's Information

Name:	Ms. Shova Shrestha
Academic Qualification:	PhD in Geography
Organization:	Central Department of Geography, TU
Current Designation:	Lecturer
Work Experience:	15 years
Published Papers/Articles:	NA
e-mail:	shova216@gmail.com