Abstract:

The objective of the study is to develop a GIS-based water infrastructure inventory (WII) for water resources assessment in the upper Srepok basin, Vietnam. The water availability and demand were estimated using common methods. Different water scarcity indicators were estimated to examine the water situation at district level under present and future conditions and future water development needs are assessed. Results reveal that the aggregated information on the basin scale misleads the issue of water situation, especially the scarcity at local level due to high spatio-temporal variations of water resources availability and demands. Most districts in the study basin will experience severe water scarcity in 2010 and 2020 in both physical and economic terms. Generated data from the WII shows very low percentage of water withdrawals in several districts with respect to available resources. Therefore, to meet future demand, significant investment in water infrastructure is needed.

KEYWORDS water resources; demand; withdrawal; scarcity indicator; infrastructure inventory

INTRODUCTION

Water scarcity is one of the major water related issues that most countries are facing or will face in the near future due to increased water demand resulting from rapid population growth, urbanization, industrialization and economic development. Many studies have been carried out to demonstrate water scarcity using different indicators. The scarcity situation is normally examined on the national/regional scale with the same assumption that the water resources are evenly distributed over the country or region. This provides misleading information with, in most cases, analysis indicating no scarcity at national/regional level.

In addition, water resources planners and managers are faced with problems of lack of data and information to assess the status of water resources at local level because required data are managed by different government agencies with little or no exchange. Recently, GIS technology has widely been adopted as an essential tool for the effective use and display of geographic information. Hence, there is a need to develop a GIS-based water infrastructure inventory (WII) to overcome these problems. Furthermore, this inventory will also be extremely useful in developing suitable water development policies for a region.

The purpose of this study is to utilize the effectiveness of a GIS-based WII in the assessment of water resources on district scale in a mountainous basin in the Central Highlands of Vietnam. This is achieved by establishing an inventory of existing water infrastructures using GIS to assess water withdrawals; by estimating water availability and water demand of different water user sectors; and by analyzing and mapping the spatial distribution of water situation, water scarcity indicators and proposed future water development in the study area.

STUDY AREA AND DATA

Study area

The Central Highlands of Vietnam (CHV) lie approximately between 12° to 15°N and 107° to 109°E. Due to temporal variation of hydro-meteorological condition in the area with steep slopes of terrain, flash floods in the wet season (June to November) and droughts in the dry season (December to May) are common in the study area. In addition, with high immigration rates from other provinces and rapid local population growth since 1976, the expansion of agricultural area has occurred in an uncontrolled manner. Forest cover in Dak Lak province (DL)—one of the five provinces in CHV, on the contrary, declined by 25% between 1975 and 2000 (Muller, 2003). Consequently, water demand for agriculture has increased significantly and dominated with more than 85% the total water demands. Moreover, over-exploitation of groundwater for irrigation and increased unauthorized boreholes have led to a decline in the groundwater level, for example 2m from 1997 to 2003 at Buon Ma Thuot (BMT) city, DL (World Bank, 2003).

The Srepok river, a tributary of the Mekong river, is one of the main rivers in CHV. It passes through Cambodia before merging into the Mekong. The Srepok basin, a representative of the mountainous area in the CHV in terms of hydrologic characteristics and water related problems as mentioned earlier, was selected for this study. The basin area in Vietnam is 18,200 km², of which 11,996 km² is the upper Srepok basin with the population of 1,732 million (2006). The study area was divided into 6 sub-units as shown in Figure 1.

In the study area, the elevation decreases from east-south to west-north. The terrain is complex whereas plains are mixed with valleys. High mountains are in the south and east-south with average elevations rang-
Data manipulation and analysis: attribute data were collected data and their sources are summarized in Table I. The data on water infrastructures was collected from relevant provincial governmental offices in CHV which include Department of Agriculture and Rural Development (DONRE), Department of Natural Resources and Environment (DONRE), Dak Lak Statistical Office (DLSO), Dak Nong Statistical Office (DNSO) and Lam Dong Statistical Office (LDSO). Monthly rainfall and monthly stream flow data of nine stations, monthly basis were collected from Hydro-Meteorological Data Center (HMDC). The collected data and their sources are summarized in Table I.

METHODOLOGY

Establishment of WII database

Steps that followed in the development of WII database are described below:

1. Data acquisition and preprocessing: data collected in different formats were digitized and converted into GIS format that can directly be imported into ArcGIS Desktop 9.1 application.
2. Data manipulation and analysis: attribute data were revised and updated by overlaying to obtain necessary information on the smaller spatial scale.
3. Database: the comprehensive information of districts’ water infrastructures with maps and attribute data were all stored as GIS database format.

Data analysis

Water availability. Due to non-availability of data on water availability and demand at district level, average values based on areal proportion of sub-basins to the districts were used in this study. Although the results provided by this simple approach may not be accurate, they can be used to compare the present and future water situations, and to estimate the magnitude of water scarcity at district level.

Components contributing to the water resources of a district include (Seckler et al., 1998):

1. Surface inflow to a district generated from the rainfall within the district and inflow from surrounding districts;
2. Surface outflow: the portion of surface inflow escaping from the district;
3. Change in storage (net change in reservoir storage and groundwater storage).

Summing up (1) and (3) and then subtracting (2) results in the total runoff (available water) of a district. However, due to lack of required data, only runoff generated from rainfall was accounted in the study. Seasonal runoff was estimated at the 75 percent exceedance probability rainfall (75P), not the average or 50P. The reason is that, if 50P is used, then for a long term, the actual value will exceed the assessed value every other year. When 75P is used, on the other hand, the actual runoff in long run will exceed the estimated runoff in 3 out of every 4 years. Moreover, 75P has been used for river basin planning studies (Amarasinghe et al., 1999). Therefore, 75P was selected in this study.

To account for the effect of topographic variation on rainfall as mentioned above, the study area was divided into two zones. The first zone covers sub-basins in the northern part including Krong Buk and Main Srepok sub-basins, and the second zone covers the remainders in the south (Figure 1). The arithmetic mean rainfall of each zone was calculated assuming that the topographical variation within the zone is low and that the selected rainfall stations are evenly distributed.

Following procedure was applied in estimating runoff in sub-basins of the study area:

1. Nine rainfall stations and five stream flow stations were selected based on their spatial distribution and available data from 1978 to 2003.
2. Monthly data of selected stations were converted into seasonal values for rainfall-runoff analysis.
3. The seasonal (wet and dry) rainfall-runoff relationships of the two zones were developed by a regression analysis method assuming linear relationship.
4. From seasonal rainfall-runoff relationships, 75P of each sub-basin was used to determine seasonal runoff for each of the sub basins in the two zones.
5. For the sub-basins where rainfall data is not available, mean rainfalls of the nearby stations were used.

Table I. Data and the sources.

<table>
<thead>
<tr>
<th>Data/Theme</th>
<th>Year</th>
<th>Data type</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreholes</td>
<td>2005</td>
<td>Location, capacity, yield</td>
<td>DHEG704</td>
</tr>
<tr>
<td>Reservoirs and Diversions</td>
<td>2005</td>
<td>Location, capacity, storage characteristics</td>
<td>DARD</td>
</tr>
<tr>
<td>Population</td>
<td>2006</td>
<td>Number, district-wide</td>
<td>HMDC</td>
</tr>
<tr>
<td>Rainfall</td>
<td>1978–2003</td>
<td>9 stations, monthly basis</td>
<td>DLSO, DNSO and LDSO</td>
</tr>
<tr>
<td>Stream flow</td>
<td>1978–2003</td>
<td>5 stations, monthly basis</td>
<td>HMDC</td>
</tr>
<tr>
<td>Digital Elevation Map</td>
<td>2005</td>
<td>90m resolution</td>
<td>DONRE</td>
</tr>
<tr>
<td>Administrative map</td>
<td>2005</td>
<td>Scale 1:1,000,000</td>
<td>DONRE</td>
</tr>
</tbody>
</table>
District boundary map was superimposed on the river basin map to identify partial area of each sub-basin constituting to each district. Runoff of each district was computed based on this proportion.

Water demand. Current domestic water demand at district level was estimated using the per capita water use of 67 L/cap/day (IWRP, 2001) and the population data of 2006. Industries have not developed in this area and moreover the data on industrial water use/demand are not available. Hence, the current industrial water uses were assumed to be equal to domestic demand of districts. Present water demand of irrigation sector was estimated based on the irrigated area of each crop and crop water requirement (CWR). There are four annual crops in the basin: winter-spring rice (January to May), summer-autumn rice (June to September), soybean crop (October to December) and coffee (November to April). Monthly CWR of four crops in the two zones were estimated by IWRP (2001) using CropWat program. CWR for coffee in January, for example, are 184 and 175 mm in zone one and two, respectively. CWR of the sub-basins, and then for the districts were calculated by overlaying of maps. The estimates of irrigation demand were then made on seasonal basis.

Projected domestic water demand was estimated based on meeting at least basic water requirement (BWR) for human needs. The BWR standard for human needs of 50 L/cap/day was suggested by Gleick (1996). For Vietnam, MOC-MARD (2000) and DANIDA (2006) suggested 80 and 100 L/cap/day as domestic water demand in the basin for 85% and 100% of rural population by 2010 and 2020, respectively. Whereas, by 2010 and 2020, 100% of urban population will use clean water of the national quality standards of 100 and 120 L/cap/day, respectively. The latter suggested values are used in the present study. The population was projected using the current population and the growth rate of 1.4% (IWRP, 2001). Projected industrial water demand for 2010 and 2020 was assumed to be the same as the projected domestic water demands. Irrigation water demand in 2010 and 2020 of each sub-basin and district was estimated based on CWR and the projected irrigated area of the four main crops. The irrigated area was proposed to increase from 172,386 ha in 2006 to 229,134 and 380,082 ha in 2010 and 2020, respectively. Especialy, coffee area has been expanded rapidly from 7,713 and 9,734 × 10^6 m² in 2006, 2010 and 2020, respectively. The estimated water deficit/surplus in the dry season. Water deficit/surplus in the wet season and some districts (14 in 2006; 12 in 2010 and 6 in 2020) in the dry season. Water deficit/surplus in the dry season is shown in Figure 2. Distribution of existing water infrastructures in the
basin is shown in Figure 3. The figure reflects that water resources development in the basin has played an important role in the expansion of agriculture in the basin. However, the distribution of water infrastructure is not uniform across the districts in the basin. There are 484 reservoirs and 76 diversion dams with a total reservoir storage capacity of $280 \times 10^6$ m$^3$. Total irrigated area for rice, coffee and other crops was 71,300 ha, of which coffee’s irrigated area accounted for more than 70%. The number of production groundwater boreholes is 386, of which 111 boreholes are located in BMT city. Total estimated water withdrawal was $1,169 \times 10^6$ m$^3$, of which more than 93% was used by the agricultural sector. Annual per capita water withdrawal in the basin is 441 m$^3$. Percentage of annual water withdrawals with respect to water availability was found to be very low (only 10% on the basin scale). Based on the current water situation, future water resources development in several districts is proposed to meet future water demand. This indicates that a significant investment in water infrastructures in almost all districts is urgently needed to improve the water supply situation which will help enhance quality of life of the local people.

**Water scarcity indicator**

The levels of water scarcity on the basin and district scales and on the annual and seasonal basis are presented in Table III. In this table, the letters “N”, “M”, “MS” and “S” show the level of water scarcity and stand for no or little, moderate, medium to severe and severe water scarcity, respectively. The letters “MS” and “M” under the IWMI criteria indicate severe economic and moderate economic water scarcity, respectively. On the district scale, the number before “S”/“MS” indicates the number of districts that are or will fall from severe/medium to severe water scarce level, and that in the parentheses after “S”/“MS” stands for percentage of total area/population of districts that is or will fall from severe/medium to severe water scarce condition.

According to the Falkenmark’s criteria, although both current and future per capita annual water availability show little or no water scarcity on the basin scale, about 23% of the total population occupying 4% of the total land of BMT city has been in the situation of medium to severe water scarcity in 2006 and 2010. Based on the UN’s criteria, on annual basis, the number of districts with severe scarcity level will increase from 5 in 2010 to 11 in 2020. On seasonal basis, even in the wet season, several districts will fall under severe water scarcity category in 2010 and 2020. If the IWMI’s criteria is considered, on annual basis and on the basin scale, medium to severe water scarcity will prevail in this study area in the future. At the district level, 23 and 57% of the total population will be in severe scarcity situation in 2010 and 2020, respectively. Even in the wet season, two and five districts will suffer from severe water scarcity in 2010 and 2020, respectively.

Comparing the three indicators, it can be seen that, at basin level, only UN indicator suggests severe annual water scarcity in 2020. However, several districts are experiencing serious water scarcity at present or will be in this category by the year 2010 and 2020. The Falkenmark indicator shows that almost 80% of the total population in the basin has high per capita water availability with no severe scarcity. Some districts show high per capita available resources but UN and IWMI indicators identify them as severe water scarce due to high demand with respect to available resources. Moreover, some districts may have high annual per capita water availability and low level of withdrawal compared to water availability. These districts are not identified to face a scarcity situation under the
Table III. Levels of water scarcity on the basin and district scales.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Annual Falkenmark</th>
<th>Annual UN</th>
<th>Annual IWSM</th>
<th>Seasonal Falkenmark</th>
<th>Seasonal UN</th>
<th>Seasonal IWSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin: 2006</td>
<td>N</td>
<td>M</td>
<td>–</td>
<td>N</td>
<td>MS</td>
<td>–</td>
</tr>
<tr>
<td>2010</td>
<td>N</td>
<td>MS</td>
<td>MS</td>
<td>M</td>
<td>S</td>
<td>MS</td>
</tr>
<tr>
<td>2020</td>
<td>N</td>
<td>S</td>
<td>MS</td>
<td>MS</td>
<td>S</td>
<td>MS</td>
</tr>
<tr>
<td>District: 2006</td>
<td>1S (4/23)</td>
<td>25 (6/13)</td>
<td>–</td>
<td>0S</td>
<td>7S (25/60)</td>
<td>–</td>
</tr>
<tr>
<td>2010</td>
<td>1M (4/23)</td>
<td>55 (14/24)</td>
<td>5S (14/23)</td>
<td>4S (15/23)</td>
<td>13S (71/84)</td>
<td>2S (4/7)</td>
</tr>
<tr>
<td>2020</td>
<td>2M (11/25)</td>
<td>11S (56/77)</td>
<td>7S (24/57)</td>
<td>5S (14/23)</td>
<td>18S (100/100)</td>
<td>5S (14/23)</td>
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</tbody>
</table>

N: Little or no water scarcity; M: Moderate water scarcity; MS: Medium to severe water scarcity; S: Severe water scarcity.

The number before “S”/“MS” indicates the number of districts that are or will fall from severe/medium to severe scarcity level, and that in the parentheses after “S”/“MS” stands for percentage of total area/population of districts that is or will fall from severe/medium to severe water scarce condition.

“Wet” and “Dry” are the wet season (June to November) and the dry season (December to May), respectively.

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REFERENCES


