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ORIGINAL PAPER

Hydroecological approach for determining the width of riparian buffer zones for providing soil conservation and water quality

T. Dindaroğlu · M. Reis · A. E. Akay · F. Tonguç

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Abstract Riparian buffer zones have important ecological functions such as sustainability of water quality, reducing sediment accumulation, and preventing erosion. However, it is often very difficult to develop a general rule for these areas since each riparian zone may have different rainfall characteristics and soil properties. In this study, the width of riparian buffer zone was determined around a sample dam lake to achieve sustainable water quality and soil conservation. The research was conducted in Palandöken Dam Lake located in the eastern city of Erzurum in Turkey. For the implementation of the riparian buffer zone, firstly, flood conditions were taken into account based on series of satellite images and then *depression zone* was calculated using Arc-hydro software based on Digital Elevation Model. Two satellite images of the study area taken in August 2008 and April 2011 were compared to determine the potential flooded areas. Then, potential *depression zone*, which are around and beyond the flooded areas, were determined based on terrain structure (sink areas). Finally, the width of the riparian buffer zone was determined by including reserve zone and management zone onto the *depression zone*. The results indicated that depression area was 5,774 ha. The area and perimeter of riparian buffer zone were 6,364 ha and 59 km, respectively. It was found that hydroecological approach using geographical information system technology can be successfully implemented to provide maximum sustainable protection of water and soil resources in riparian zones, especially in the lake basins.

T. Dindaroğlu (✉) · M. Reis · A. E. Akay · F. Tonguç
Department of Forest Engineering, Faculty of Forestry, Kahramanmaraş Sütçü İmam University, 46100 Kahramanmaraş, Turkey
e-mail: turgaydindaroglu@hotmail.com

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Introduction

The term of riparian is originated from Latin word of "*riparius,*" which means "*of or belonging to the bank of a river*" (Naiman and Decamps 1997). Riparian zones, as interfaces between terrestrial and aquatic systems, are dynamic and complex environments that have many purposes and benefits. Riparian zones are defined as an ecological complex where flood plains and wetland area are adjacent to waterways or lands (Parson 1991; Walker 1993). These zones are vital for enhancement of biodiversity and protection of forest ecosystems (Akay et al. 2012). The hydroecological benefits of riparian zones include stabilizing the soil, protecting water quality, reducing erosion, preventing sediment and pollutants delivery to streams, and reducing surface water flow rates. Besides, riparian buffer zones provide better habitat for wildlife and enhance scenic value and intrinsic values (Quinn et al. 1997; Mark and Planner 2003; Hairsine and Grayson 1992; Allen 1978).

The riparian buffer areas are divided into two buffer zones including reserve zone and management zone (Poulin et al. 2000). In reserve zone, the human development, agriculture, and forestry operations are restricted, while only ecologically acceptable forestry operations can be applied in the management zone (Akay 2010). Forestry practices such as afforestation, regeneration, maintenance etc. should be implemented only to protect reserve zone and to ensure sustainable use of management zones. There is a positive correlation between capabilities of riparian buffer zone and available vegetation type along the riparian zone and the width of the zone (Wenger 1999). There are two broad types of vegetation in riparian buffer zones including forests and grasslands. Frequent erosional disturbances from flooding may result in a variety of soil conditions that fundamentally influences establishment of the vegetation types (Oliver and Larson 1996). The width of the riparian buffer zones vary based on terrain conditions, type of the water bodies, beneficial uses, and existence of aquatic life (Akay et al. 2012). Site-specific conditions are also important factors in determining appropriate riparian buffer zones. In general, wider the buffer zones lower the amount of sediment and pollutant delivery (Young and Huntrods 1980; Peterjohn and Correll 1984; Dillaha et al. 1988, 1989; Magette et al. 1989; Wenger 1999). Determining the width of the riparian buffer zones used digital elevation models (DEM). DEM defines location of water surface area and delineates flood area, sediment yield, water quality, and hydrolic networks.

In previous studies, the riparian buffer zone starts from the edge of the water bodies. However, depression zone located beyond this point can cause serious problems in terms of soil conservation point of view. Thus, riparian buffer zones should start from depression zone to prevent possible impact on soil. Depression evaluation algorithms created as D8 (O'Callaghan and Mark 1984) was developed by Jensen and Domingue (1988), currently implemented in GIS such as TOPOZ (Garbrecht and Martz 1997), HEC GEO-HMS (USACE 2002), Arc Hydro Tools (Maidment 2002), and GRASS (Neteler and Mitasova 2008).

A new riparian zone based on satellite image and using fuzzy approach is planned. The model includes spectral, land use and topographic information to derive riparian zones (Clerici et al. 2011). Seasonal climate changes and geomorphology have an important role in movement surface water (Thorndycraft et al. 2008). Hence, Landsat

Fig. 1 The location of the study area

ETM+ and SPOT data are used to determine the surface water layer with European water mosaics based on spectral classification (Baraldi et al. 2006; Kempeneers et al. 2010).

The main objective of this study was to determine the width of riparian buffer zone around a sample dam lake based on hydroecological approach using GIS technology. The study was implemented in Palandöken Dam Lake that has been used as a source of drinking water and irrigation in the province of Erzurum, Turkey. The width of the riparian buffer zone was determined by including reserve zone and management zone onto the *depression zone*. This approach has great potential to determine appropriate riparian corridor that ensures sustainable water quality and soil conservation.

Materials and methods

Study area and GIS data

This research was carried out around the dam lake of the Palandöken, which is located in the eastern city of Erzurum, Turkey. The bounding geographical coordinates of the study area are 39°40′51″–39°41′50″ north latitudes and 41°00′65″–41°09′98″ east longitudes (Fig. 1). The area of the lake watershed is 23,351 ha.

A digital elevation model (DEM) of the study area was derived from the topographic map with a scale of 1:25000. The DEM was used to produce slope map using ArcGIS 10 (ESRI 2010). Collins et al. (2006) and Sutula et al. (2006) used digital elevation models and supplementary data to recognize geomorphological breaks to represent riparian zone areas. The surface water levels in last decade of Paladöken Dam Lake were analyzed. The minimum and maximum lake water level were discovered in the August 2008 and April 2011, respectively. Two satellite images (Landsat ETM+) acquired in August 2008 and April 2011 were used to determine surface area of the dam lake before and after flooding. Evaluating depression areas could encounter some difficulty in determining flow directions (Jensen and Domingue 1988). So, DEM optimization was performed with Agree-DEM method (Maidment and Djokic 2000; Maidment 2002). DEM datasets were derived from the original 25 m resolution DEM data (1:25000). An inverse distance weighted (IDW) interpolation technique—the technique in which values at unknown places are calculated from known places using a weight function—(Philip and Watson 1982; Hudson and Wackernagel 1994; Holdaway 1996) was used to create a continuous width of the buffer zone surface. The IDW formula is as follows:

$$\hat{Z}(s_0) = \sum_{i=0}^{N} \lambda_i Z(s_i)$$

where $\hat{Z}$ (s_0) is the value to be predicted for s_0 location. N is sampled points around the prediction location λ_i are the weights assigned measured point. Z (s_i) is the observed value at the location s_i. Determined weights for known values are used in the following formula:

$$\lambda_i = \frac{d_{i0}^{-p}}{\sum_{i=1}^{N} d_{i0}^{-p}} \sum_{i=0}^{N} \lambda_i = 1$$

The quantity $\boldsymbol{d_{i0}}$ is the distance between the predicted location, $\boldsymbol{s_0}$, and each of the measured locations, $\boldsymbol{s_i}$. Weighting of the sampled point depends on the parameter p, distance increases; the weight is reduced by a factor of p (Burrough and Mcdonnell 1998).

Forest management maps (1:25000 scale) was also used to generate land use type of the study area.

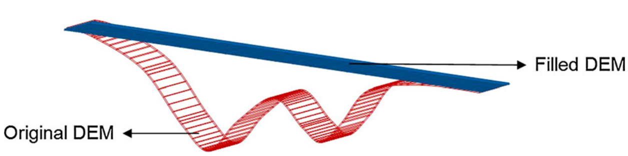

Fig. 2 Filled and original DEM used in depression evaluation

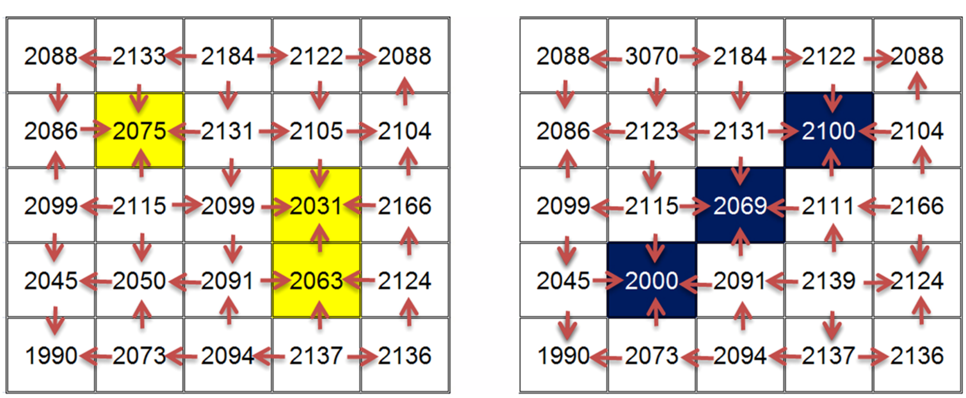

Fig. 3 Depression evaluation algorithms (*Left side*: Fig. 3a, *Right side*: Fig. 3b)

GIS analysis (evaluation depression zone algorithm)

The "*Depression Evaluation*" function under "*DEM Manipulation*" menu of ArcHydro 2.0 Maidment (2002) was used to generate the depression zone. Depressions zone is defined by subtracting the original DEM from the filled DEM (Fig. 2).

Filled DEM was generated by filling sinks in the original DEM using ArcHydro 2.0. Then, based on the filled DEM, flow direction grid was produced to generate the drainage areas associated with the depression zone. Because of the other depression areas in the basin is an independent area, riparian zone does not affect these areas directly. Depression areas are selected with connection areas of the current lake area for evaluating riparian zones.

Depression evaluation model was designed in combination with D8 flow direction algorithms. Flow paths demand on x- and y-directions are exemplified in Fig. 3 where flow directions were demonstrated by arrows. Depression cells were shown in yellow color. The yellow cells have lower altitude than other cells. If a sampling point should be evaluated from the basin area, depression

Table 1 Riparian buffer zone widths for effective soil and water conservation (Dindaroğlu 2011)

Water body	Minimum soil conservation zone (m)		Management zone (m)	Riparian buffer zone (m)
	Depression Zone	Reserve zone		
Lake	D.Z[a]	10	90	D.Z + 100

[a] D.Z.: Depression zone width varies based on terrain conditions

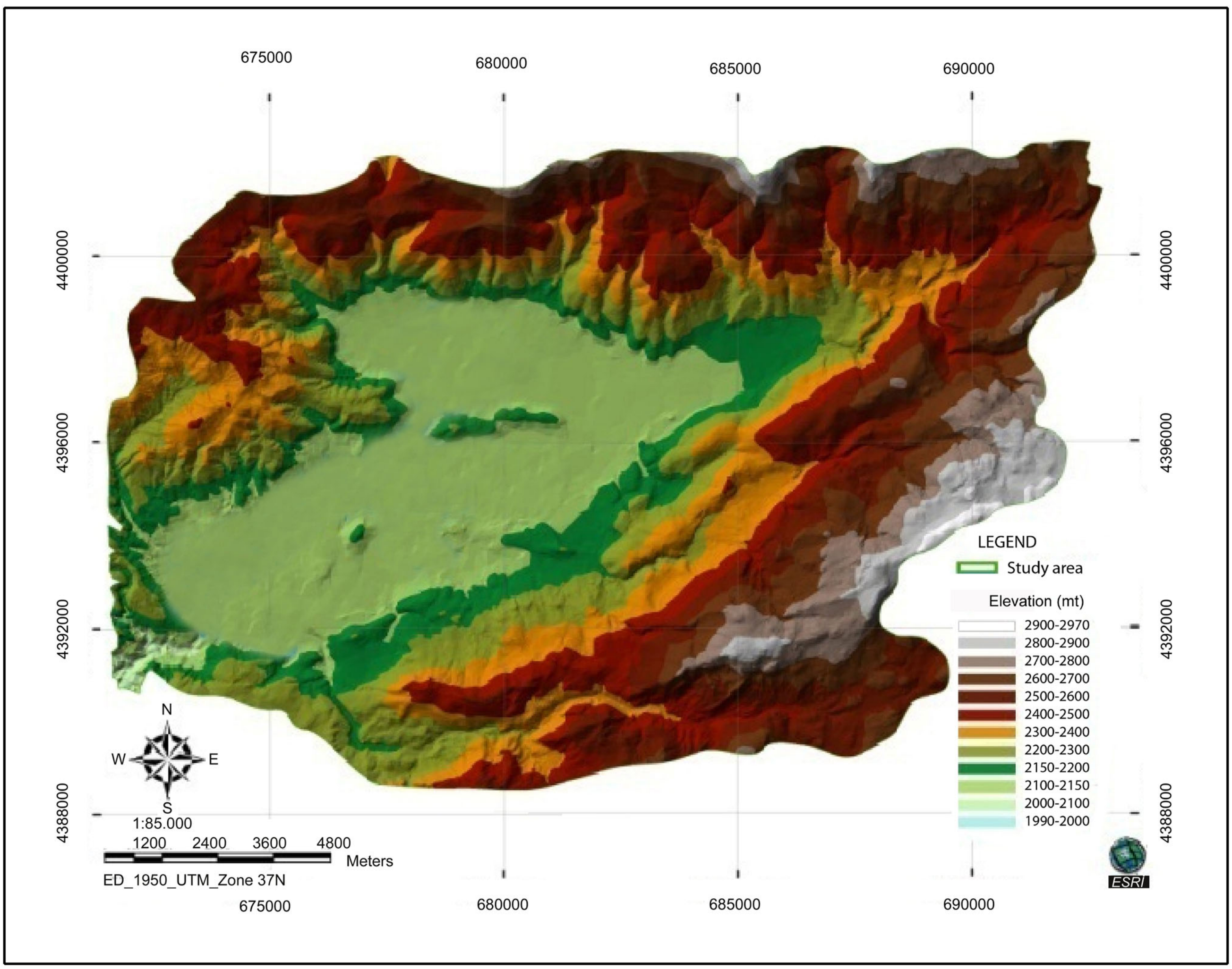

Fig. 4 DEM of the study area

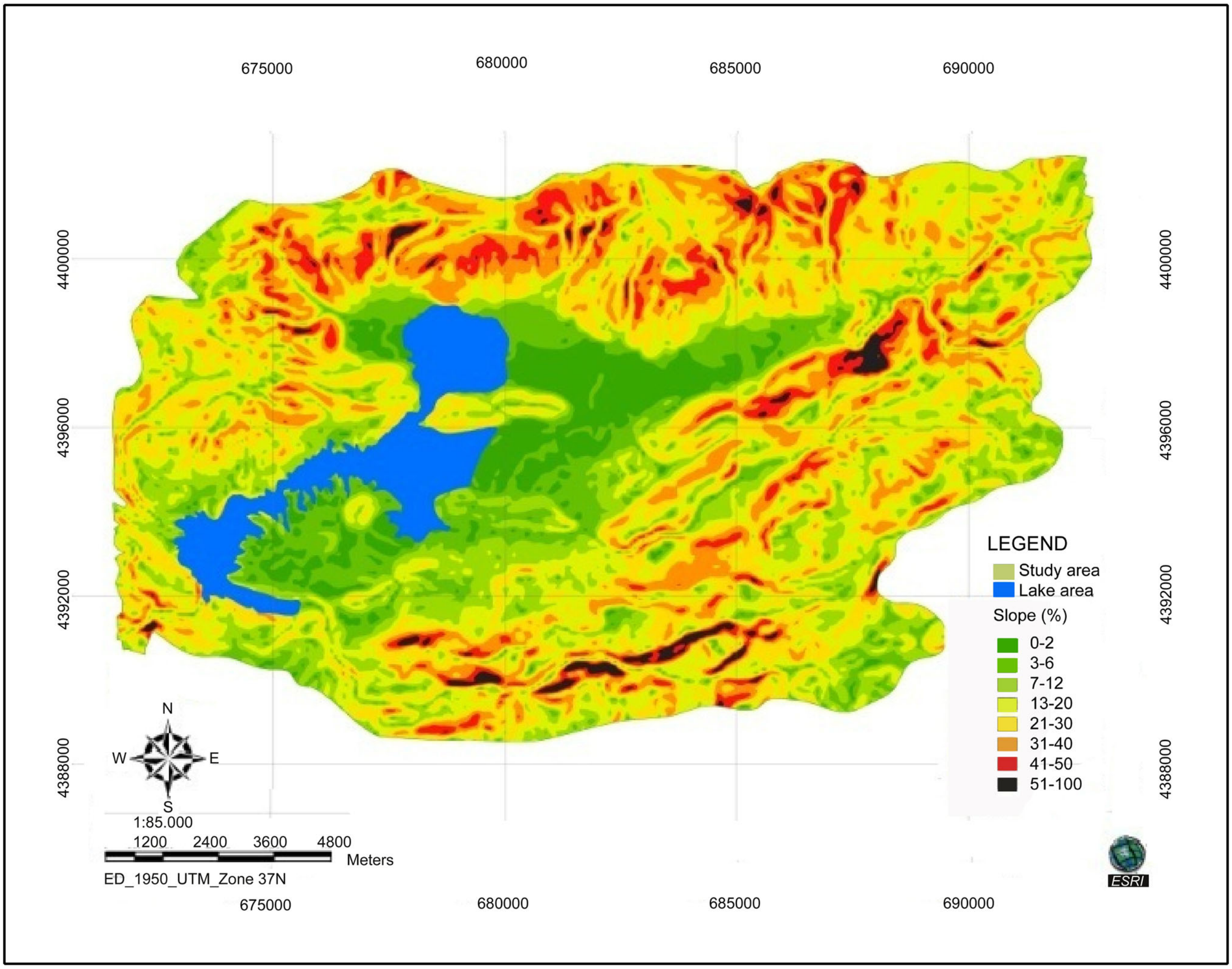

Fig. 5 Slope map of the study area

areas required minimum 2,086, 2,091 and 2,099 m elevation for water flowing (Fig. 3a). The cells with altitude 2,000, 2,069 and 2,100 m are depression cells that pass to flow when water level is increased to 2,045, 2,091 and 2,111 m altitude, respectively (Fig. 3b).

Archydro tools evaluated sink cell connected with flow direction cannot be assigned to one of eight current values. This condition takes place like; neighboring cells higher than processing cell other cells flow into each other (Maidment 2002).

Digital elevation model (DEM) accuracy

Since digital data might have some amount of error associated with elevations, "*false*" depressions should be eliminated from "*true*" depression areas. In this study, the depression areas that are larger than one cell (60 m^2) and minimum 20 m away from a connected stream are characterized as "*true*" depression areas.

Riparian buffer zone

After determining potential depression zone, which are around and beyond the flooded areas, the width of the riparian buffer zone was determined by including reserve zone and management zone onto the *depression zone*. The criteria suggested by Stevens et al. (1995) and Decker (2003) and then modified by Dindaroğlu (2011) were used for determining the buffer zone width (Table 1). Based on these criteria, reserve zone width of 10 m was added to the *depression zone* for delineating minimum soil conservation zone. Then, management zone of 90 m was added to soil conservation zone to generate final riparian buffer zone.

Accuracy assessment process for depression and riparian zones

For accuracy assessment of the depression and riparian zones, control points were determined using homogeneous and randomized sample method. Accuracy of control points was evaluated from topographic maps (1/25000 scale), GoogleEarth (2013) and local field surveys.

Results and discussion

The results indicated that the base of the lake was 1,990 m, while the highest elevation of the basin was 2,970 m (Fig. 4). The slope map generated based on DEM was shown in Fig. 5. The average slope, excluding the dam lake surface area, was computed as approximately 40 %.

The results indicated that Dam Lake covers the area of 1,382 ha before flooding. Based on the April 2011 image acquired shortly after flooding total surface area of the dam lake was found to be 2,258 ha. Thus, water surface area increased by 61.20 % after flooding (Fig. 6).

The area of depression zone was calculated as 5,774 ha. The depression zone map generated by using ArcHydro module was shown in Fig. 7. The results indicated that depression zone width changed between 77 and 4,150 m.

The average width of depression zone was found to be 2,340 m. In the study area, small-scale afforestation activities had performed in the last decade. However, flooding had negative impact on plantations since afforestation area was within the depression zone (Fig. 8). Thus, afforestation activities cannot achieve the main purpose of protecting soil and water quality without considering depression areas, especially in basin areas of lakes. “Attention needs to be focussed on landscape depressions where flow concentrates, here broad well-grassed areas, which cover the entirety of the flow concentration need to be implemented. These grassed areas in combination with

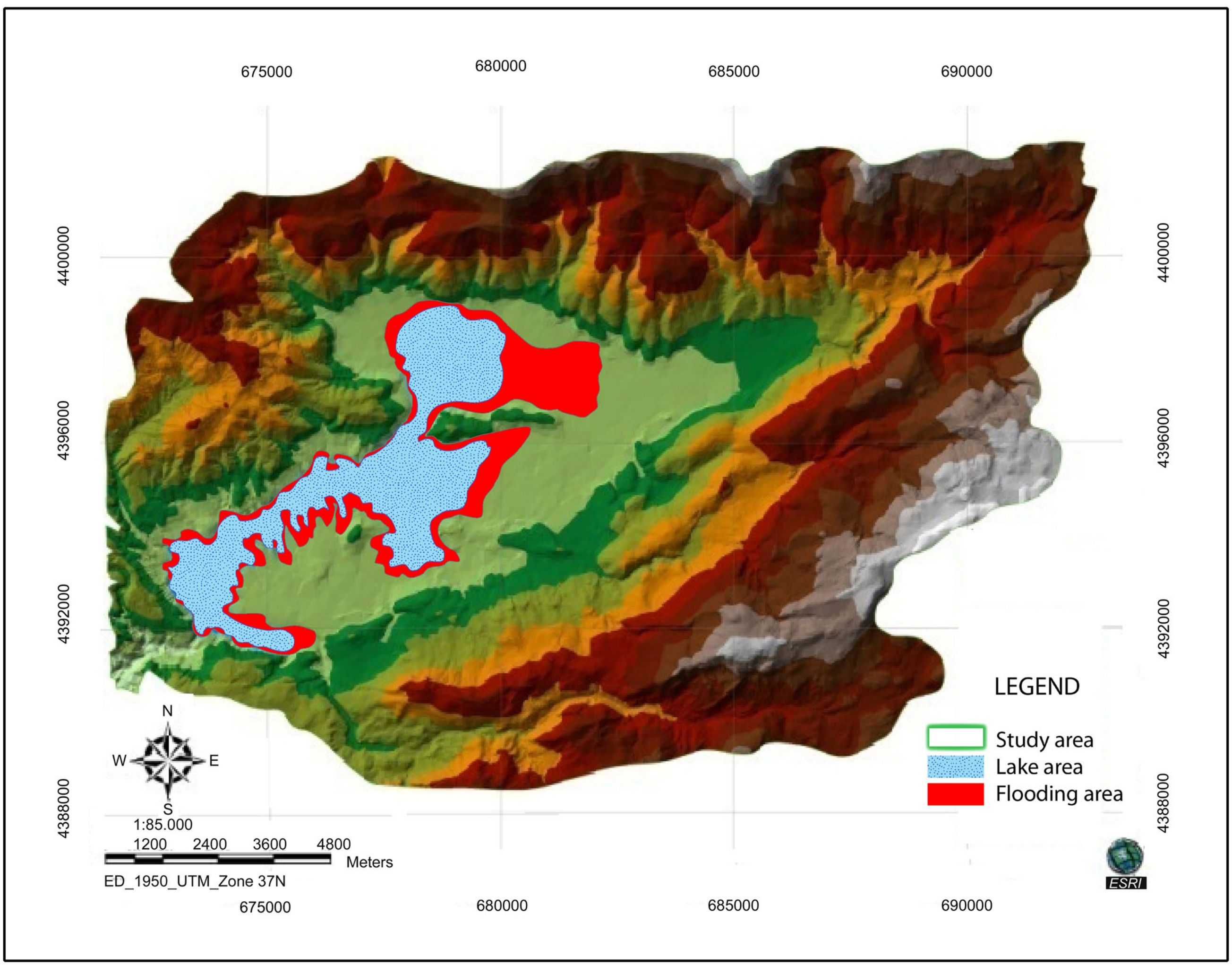

Fig. 6 Surface-water areas before and after flooding

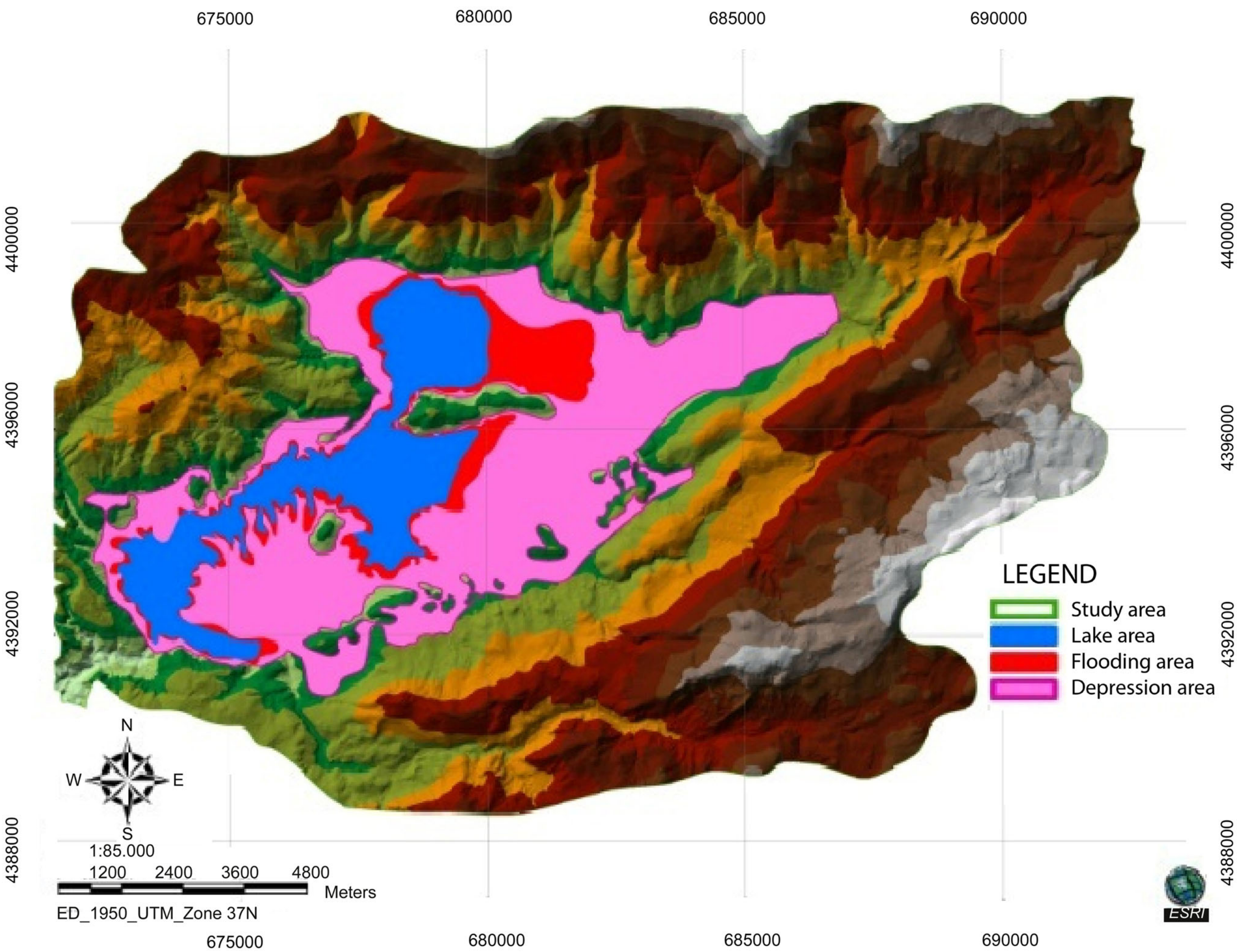

Fig. 7 Depression zone of the study area

Fig. 8 Flooded plantation areas within the depression zone

a native vegetation strip along the foreshore slow the overland flow allowing sediments to be deposited, nutrient uptake and bank stabilization" (Doran et al. 1996).

The width of the riparian buffer zone was determined by including reserve zone and management zone onto the depression zone. According to previous studies, width of the riparian buffer zones are 3–10 m, 10–20 m, 5–30 m, 20–150 m, and 30–500+ m for input of organic materials, stream stabilization, water quality protection, flood prevention, and riparian habitat, respectively (Fischer and Fischenich 2000). In addition, it was reported that riparian zone width must be minimum 500 m to observe ecological conditions in the forest riparian zones (Robins 2002; Fischer and Fischenich 2000). The habitat requirements for fauna vary widely, and the necessary buffer widths to protect all species require riparian corridors of approximately 330 ft. Furthermore, birds require large areas much greater than riparian buffer zone, that is, more than 330 ft. (Chase et al. 1995). "The width of a buffer depends greatly on what resource you are trying to protect. Scientific studies have shown that efficient buffer widths range from 10 feet for bank stabilization and stream

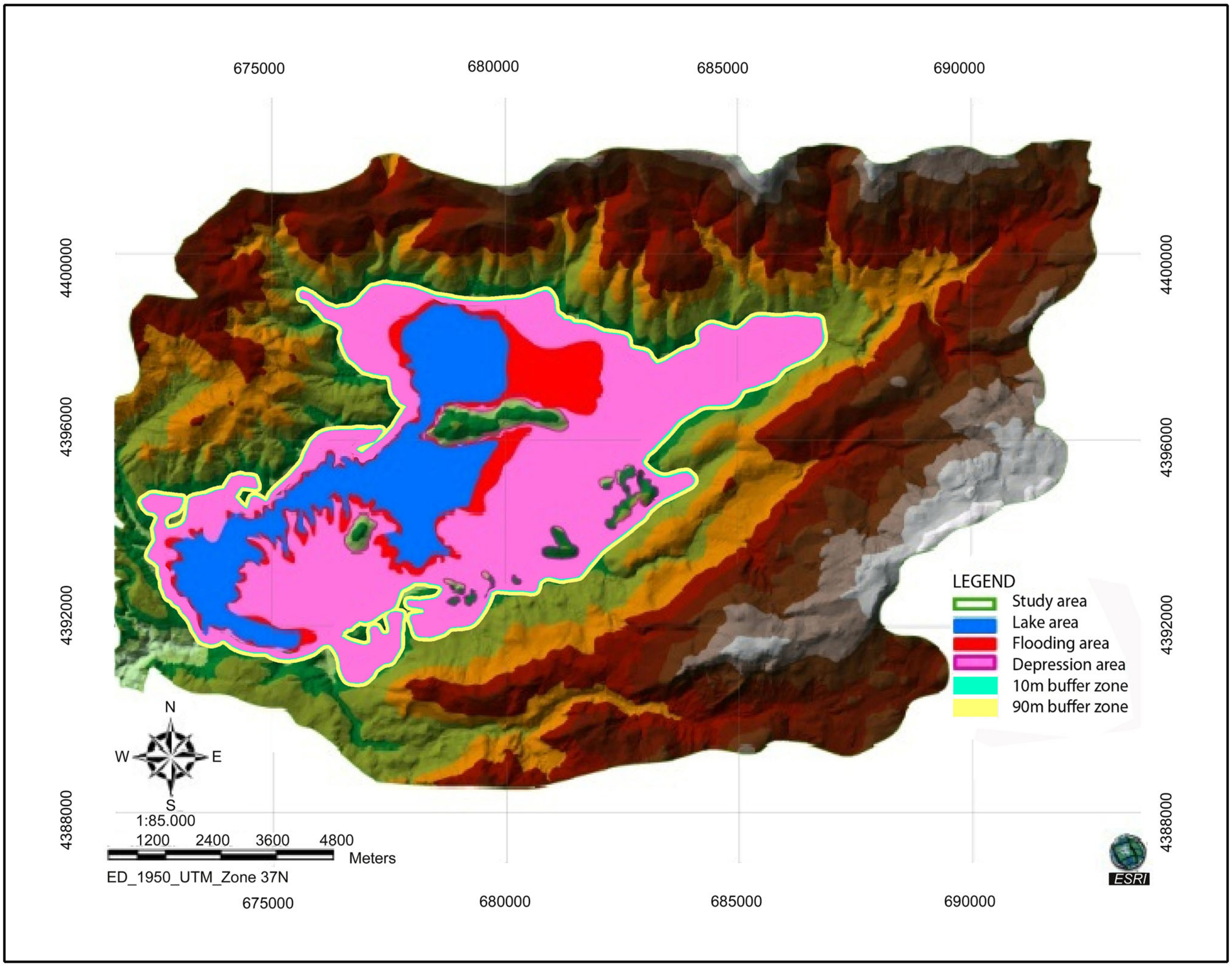

Fig. 9 Riparian buffer zone including reserved and managements zones

shading, to over 300 feet for wildlife habitat. Furthermore, the necessary width for an individual site may be less or more than the average recommendations, depending on soil type, slope, land use, and other factors" (Ellen and Markelle 2005). Appropriate mix of trees, shrubs, and herbaceous plants and other floral composition should be planted most effective for riparian buffer zones (Jontos 2004). In previous studies, the riparian buffer zone starts from the edge of the water bodies. Studies in the Mid-Atlantic support the conclusion that buffer efficiency that found most of sediments' amounts were removed by 62 ft. riparian buffer (Peterjohn and Correll 1984). In this study, it was suggested that minimum riparian buffer zone should start from the edge of depression zone. Thus, the width of the riparian buffer zone was equal to depression zone width plus 100 m (i.e., 10 m for reserve zone and 90 m for management zone). The results revealed that the area of riparian buffer zone was 6,364 ha with the perimeter of 59 km (Fig. 9).

Accuracy assessment

The accuracy assessments of the depression areas have made with 1/25000 scale topographic maps and field observations. Control points were transformed in circular polygons with 50 m diameter and imported in Google-Earth using KML format (Fig. 10). 126 control points determined homogeneous and randomized sample method. These control points were audited with the topographic maps and the field observations. Finally, 112 control points have been confirmed. Overall 88.9 % of the points were assessed as correct, while 11.1 % as wrong (false/misplaced).

Conclusion

In this study, the riparian buffer zone model proposed is based on a "*Depression area*" around the Dam Lake.

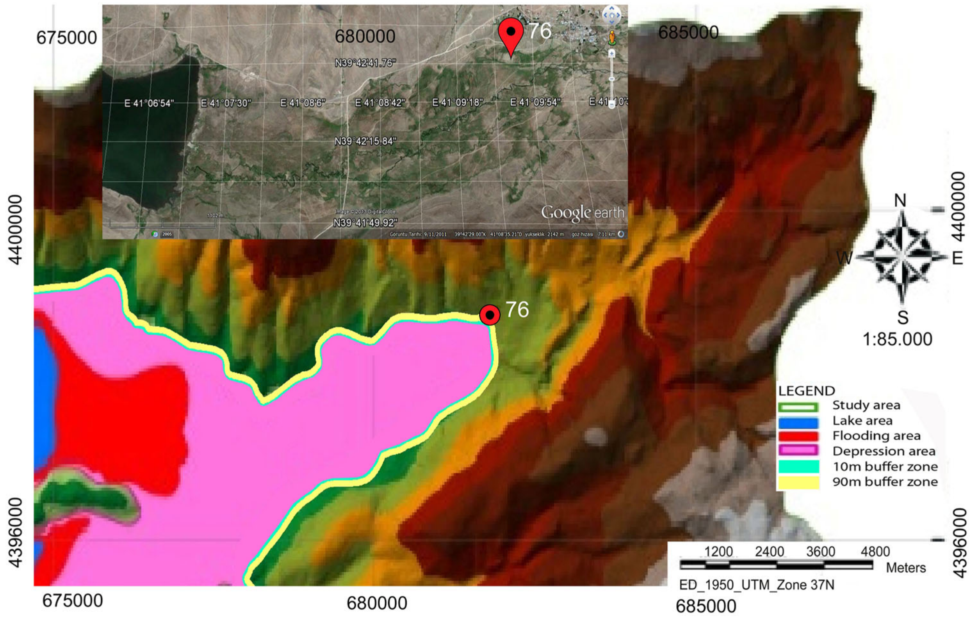

Fig. 10 Extracted control points from the Riparian buffer zone imported in GoogleEarth for visual validation

Hydroecological approach was developed to determine the width of riparian buffer zone around a sample dam lake to achieve sustainable water quality and soil conservation. Large flooded areas threaten the functionality of riparian buffer zones. In the model studied, riparian zone widths were calculated considering maximum depression zone area for sustainable riparian zone management. Although several approaches have been implemented about width of the riparian buffer zones, the approach described in this study differs from other approaches by starting riparian buffer zones from depression zone boundaries. The results indicated that the area of 2,718 ha was protected as a riparian buffer zone by implementing traditional approach, while protected area within the riparian buffer zone was 6,364 ha by implementing hydroecological approach. Therefore, using hydroecological approach increased the protected area by 234 %. Besides, considering depression zone when establishing riparian buffer zone has great potential to improve hydroecological functions of riparian zone such as stabilizing the soil, protecting water quality, reducing erosion, preventing sediment and pollutants delivery to streams and enhancing riparian habitat.

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