Geo-environmental Assessment of a Residential Land Development in Western Australia

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***Abstract*—In the present study, land suitability model has been used as a feasible methodology for geo-environmental assessment of a residential land development site in Western Australia. Geological formation, soil type and local aquifer media were considered as the main parameters affecting the geo-environment of the area. Borehole profiles along the site are used to develop geological cross sections of the site to determine the geological properties and aquifer types of the site. Soil profile data and secondary soil data are collected to determine the soil type of the land. Multi-criteria analysis is performed to evaluate the suitability of the geo-environment for each category, according to appropriately measured and weighted factors. To select an appropriate location weight of evidence model, a statistical approach was used where sufficient data are available to estimate the relative importance of each data. The total rating is converted to the land suitability index (LSI) for each category using an algorithm that combines factors. The developed land suitability index output concluded that the upper and western part of the site shows very low suitability while the lower part shows higher suitability.**

Keywords- Geo-environment, Land developments, land suitability

I. INTRODUCTION

Geo-environmental evaluations are one of the most important assessments in land use development activities and in Civil Engineering processes. Urban developments are the most critical land use developments in terms of adverse effects on environment [1]. Land development sites are categorized according to the types of land-use and planned projects. Residential developments, high-rise building, multi-story building, low-rise building, industrial zones, waste disposal and landfills, open spaces and natural conservation sites are some of the widely utilizing facilities in land developments [2], [3], [1]. Unplanned land development activities create various urban environmental problems, such as landslide susceptibility, soil erosion, environmental degradations, water quality issues and flooding [4], [5]. Therefore, it is very crucial that the land use pattern for the selected location should be carefully chosen. Therefore geo-environmental evaluations should be covered the impacts of land developments on surface, environment, ecology, water resources and groundwater.

Geo-environmental evaluations often require a large amount of spatial information. Management of large number of data including mapping data, observation data and analysis data is time consuming and difficult task. Geographic information systems (GIS) are capable of managing large amounts of spatially related information, providing the ability to integrate multiple layers of information and to derive additional information. GIS systems help the geo-environmental evaluation for different assessment stages [6], [7], [8].

This study mainly targets to use GIS as a tool in geo-environmental evaluations of residential land development and land-use planning. Impacts of land use changes on geo-environmental, context were assessed taking several features in the land development area into account. Outcome of the study will be implemented during the new land use implementation stage in terms of sustainable land developments, planning and management activities. Therefore, the objectives of this study are to design a GIS based tool for geo-environmental evaluation of a land development site located in Western Australia. The study objectives are defined to understand the adverse effect of unplanned land development on geo-environment in the area and to develop effective strategies and guidelines for land development against geo-environmental threats and their impacts. This study mainly used a land suitability index (LSI) model to facilitate the geo-environmental evaluation of the study area.

II. STUDY AREA

The case study area is a residential land development site at Brokton. Brookton is a regional city in Western Australia; locates approximately 135 km away from the Perth city (Figure 1). The land proposed to develop located north of the Brookton town with a size of 3.2ha. The land locates within Avon river catchment, which is a very sensitive environmental region in Western Australia. A significant portion of land is originally thing forest land; some minor portions of the land easements are proposed to be used for major flood event mitigation storage. The natural vegetation condition of the site currently consists of open paddocks and some remnant bush land. A natural wetland is located at the north eastern boundary of the site. Surface water flows from the north and east of the site will discharge to the Avon River south branch. The site is generally undulating and slopes gently from an elevation of 21 m AHD near the center of the site close to the western border to an elevation of 9 m AHD within the southern portion of site. The portion within the site covering the northern low elevation land ranges in elevation from 13 m AHD to 10 m AHD adjacent to the Avon River.

The development map illustrating the current condition and sub-division cadastral boundaries of the site is provided in Fig 2. The proposed subdivision structural plan for the area has a mixture of residential housing densities and public open space (POS) areas. The residential lots consist of 59 low density and medium density dwelling types with an average lot size of 400m2. A mixture of road and laneways are proposed to be used within the development with 15m wide reserves utilized for most of the development. Medium density lots were assumed to have 85% impermeable area and low density lots 75% impermeable area. Roads with 58% impervious surfaces and public open spaces (POSs) having 100% permeability was the assumed land use for rest of the land. 10% of the total land being developed has been kept for public open spaces (POS) according to the guidelines provided by WAPC [9].

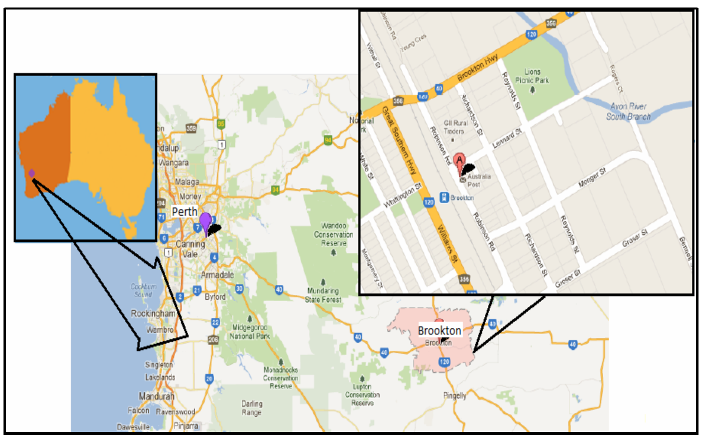

Figure 1. Study area: Brookton, WA

Figure 2. Land development map and sub-division cadastral boundaries

III. METHODOLOGY

Land suitability index (LSI) is used as the main method to assess the impacts of the land development on geo-environment. Data collection and data management was one of the most important tasks in this study. Initial stage of the study was mainly targeted on data collection. It includes collection of secondary data, field visits, geological explorations and literature review. The geo-environment evaluation usually incorporates topography, surficial and bedrock geology, surface soil, water and groundwater conditions, and ecological characteristics of the land. This study used geology, soil and aquifer media as the main components in land suitability index.

Borehole profiles along the site are used to develop geological cross sections of the site to determine the geological properties and aquifer types of the site (Fig 3). Soil profile data and secondary soil data are collected to determine the soil type of the land. Soil characteristics defined by Department of Agriculture in Western Australia is used as the main guideline for soil assessment [10]. Most of the collected data is available in digitized format; especially GIS and satellite data are integrated to generate spatial maps and spatial data layers.

Geo-environmental assessment method mainly consists of Multi-criteria analysis is performed to evaluate development suitability of the geo-environment for each category, according to appropriately measured and weighted factors. To select an appropriate location weight of evidence model, a statistical approach was used where sufficient data are available to estimate the relative importance of each data. The total rating is converted to the land suitability index (LSI) for each category using an algorithm that combines factors in weighted linear combinations using GIS tools. The summery of rating assigned is presented in the description of each parameter. After assigning the ratings for each of the features, the land suitability index (LSI) is developed according to the importance of the parameters.

Land suitability index (LSI) is defined as;

$$LSI = (G_R \times G_W) + (S_R \times S_W) + (A_W \times A_R) \quad (1)$$

Where w is weighting factor, R is rating, G is the geological type, S is the soil type and A is the aquifer type.

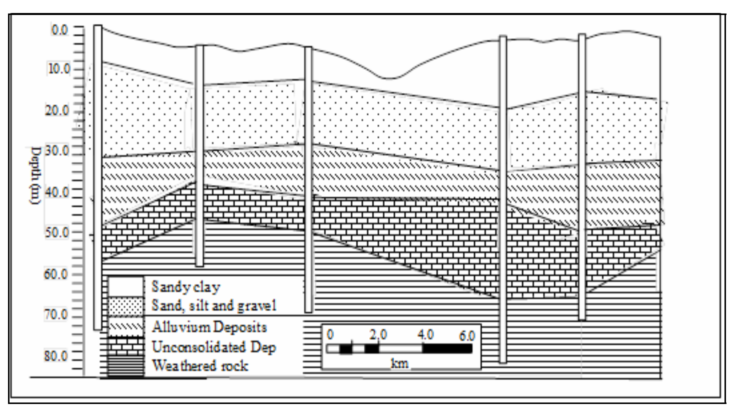

Figure 3. A geological cross section of the site

IV. RESULTS AND DISCUSSIONS

Collected data was separated into groups based on their effects on geo environmental. Three main groups are defined in this study as; geological pattern, soil type and aquifer media, which mainly affects the geo-environment. Each group is subdivided into several subgroups and itemized. Based on their effects on geo-environment, each group is given a rating as explained below.

A. Geological pattern

Geological type has been designated by descriptive names according to the available geological groups in the study area. The data related to the geological type was obtained from the literature and collected data of the geology exploration reports. The geological type available in the study was classified into the following groups. The ratings were assigned based on the defined impacts on each geological type on geo-environment as shown in Table 1.

Quartzite and Pegmatite media is a sub group of igneous rock aquifers and typical rating (3) was assigned. Unconsolidated material, commonly termed ‘regolith’, which is derived by weathering of the underlying consolidated bedrock is primary porous. This category was assigned with rating (3). Limestone or dolomite bedrock is characterized by crystalline limestone and shale sequences. The rating (6) was assigned to this class. Littoral sand with sandstone bedrock is porous and permeable and it was assigned typical rating (6). The river Alluvium was assigned rating (8) considering the presence of moderate to well- sorted deposits and associated high permeability. Unconsolidated mixture of sand and gravel sized particles which contain varying amount of fine materials, Sand and gravel which have only small amounts of fine materials are termed ‘clean”. Commonly the rating (8) was assigned to the class of gravel sand geological formation. Some geological areas with large openings interconnected cavities and fractures have the highest pollution potential and it was assigned with the highest rating (10).

TABLE I. RATINGS FOR GEOLOGICAL PATTERN

Geological pattern	Rating
Quartzites and Pegmatite	2
Regolith	3
Crystalline limestone.	6
Littoral sands	6
Alluvium	8
Sand and Gravel	8
Major faults, joints, shear and extensive fractures	10

B. Soil type

Soil is defined as the upper weathered zone of the earth, which averages a depth of six feet or less from the ground surface. Soil has a significant impact on geo-environment as land developments significantly change the soil type of the site. Infrastructure development of the area mainly changes the soil type with imported landfill materials and construction materials. Therefore soil type of the site is given very important consideration in this assessment.

With reference to the soil maps of the area the soil types were classified into groups (Table 2). Clay consists of the highest amount of clay and the permeability is very low. This was assigned with the lowest value of rating (1). Sandy clay is the soil consisting of higher percentage of clay and small amount of sand. It has a low pollution potential and rating (2) was assigned. The soil consists of fine, dark color, well-decomposed organic material that typically contains a higher mineral or ash content. The organic matter content may be a significant factor for lowering the pollution potential. Therefore organic and decomposed materials were assigned with lower rating (3). The rating (6) was assigned for clayey sand soil group. Soil contains high amount of quartz fragments and gravel, but significant amount of clay. Due to clay the permeability is lower than gravelly sand, but still considerably high. The rating (7) was assigned for clay with quartz fragments and gravel. Gravelly sand is a particle based size classification, classified by particle larger than 2mm in size. Gravelly sand commonly include a mixture of sand, silt, clay and gravel particles and it was assigned the highest rating (9). Table 2 shows the assigned rating for each soil type.

TABLE II. RATINGS FOR SOIL TYPE

Soil type	Rating
Clay	1
Sandy Clay	2
Organic / decomposed materials	3
Clayey sand	6
Clay with quartz fragments and gravel	7
Gravelly sand	9

C. Aquifer type

Aquifer media is considered taking its impact of groundwater into account, as groundwater is a primary component of geo-environment. Quantity and quality degradation of groundwater inversely affects the environment. Most of the land developments severely change the groundwater condition due to land level changes, soil compaction and site dewatering. Aquifer media refers in this study to the consolidated or unconsolidated rock which serves as an aquifer. The type of aquifer type determines the attenuation characteristics of the material below the typical soil horizon and above the water table. The aquifer type was classified according to the data obtained from borehole logs. Considering relevant properties defined in the study, the relative ratings were assigned (Table 3).

A deposit of silt and clay sized particle serves as a barrier to retard movement of liquids. The high clay content provides a low pollution potential. Value (3) was assigned for the range of sand, silt and clay. Aquifer of metamorphic origin contains no significant primary porosity and permits movement of liquid through fractures. Rating (4) was assigned to Biotite (Metamorphic rock) aquifers.

Sand and gravel with significant silt and clay layers are unconsolidated mixture of sand and gravel contains an appreciable amount of fine materials. These deposits have a high concentration of clay, thereby reducing the permeability of the deposits. Typical rating (6) was given to that range. Limestone or dolomite, which typically has fewer bedding planes, is primarily porous and it was assigned with rating (6). Mixture of large size gravel contains only a small amount of fine materials. The range in rating reflects principally a grain distribution and larger grains have a higher pollution potential. The boulders and rubbles assigned a higher rating (9).

TABLE III. RATINGS FOR AQUIFER TYPE

Aquifer type	Rating
Fresh rock	1
Sand, silt and clay	3
Biotite (Metamorphic rock)	4
Sand and Gravel with significant silt and Clay	6
Limestone	6
Boulders / Rubbles	9

After identifying ratings for each factor, the potential impact of each factor on geo-environment was evaluated taking a weighting factor into account. To select an appropriate weight of affecting parameters, a statistical approach was used where sufficient data are available to estimate the relative importance of each parameter. Table 4 shows the weighting factor assigned for each parameter. The total rating is converted to the land suitability index (LSI) for each category using an algorithm that combines factors in weighted linear combinations using GIS tools. The summery of rating assigned is presented in the description of each geo-environmental parameter. After assigning the ratings for each of the features, the land

TABLE IV. WEIGHTING FACTORS FOR LAND SUITABILITY INDEX (LSI)

Geo-Environmental parameter	Weighting Factor
Geological characteristics (G)	3
Soil media (S)	5
Aquifer media (A)	2

The study area was divided into 20 m × 20 m grids to apply the effect of each LSI parameter and the grid coverage was prepared in GIS environment. Selected three LSI parameters were overlayed to form a single resultant value. The step by step procedure was followed to overlay each of the features as explained in methodology.

The final LSI coverage determines the impacts of land development on geo-environmental behaviour of the area. The LSI is classified as follows to determine the potential impact on geo-environment.

TABLE V. LAND SUITABILITY INDEX (LSI) AND SCALE OF THE IMPACT

Scale of the impact	Land Suitability Index
Very low impact	13 -25
Low impact	25 -40
Moderate impact	40-60
High impact	60-75
Very high impact	75-93

V. CONCLUSIONS

As unplanned land development activities create various urban environmental problems, such as landslide susceptibility, soil erosion, environmental degradations and water quality, geo-environmental evaluations are one of the most important assessments in land use development activities. Therefore geo-environmental evaluations should be covered the impacts of land developments on surface, environment, ecology, water resources and groundwater. In the present study, land suitability model has been used as a feasible methodology for geo-environmental assessment of a residential land development site in Western Australia. Geological formation, soil type and local aquifer media were considered as the main parameters affecting the geo-environment of the area. Borehole profiles along the site are used to develop geological cross sections of the site to determine the geological properties and aquifer types of the site. Soil profile data and secondary soil data are collected to determine the soil type of the land. Multi-criteria analysis is performed to evaluate the suitability of the geo-environment for each category, according to appropriately measured and weighted factors. To select an appropriate location weight of evidence model, a statistical approach was used where sufficient data are available to estimate the relative importance of each data. The total rating is converted to the land suitability index (LSI) for each category using an algorithm that combines factors. The developed land suitability index output concluded that the upper and western part of the site shows very low suitability while the lower part shows higher suitability.

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